Effect of palm kernel expeller supplementation on production performance of Jersey cows grazing kikuyu/ryegrass pasture

by

Josef de Villiers van Wyngaard

Submitted in partial fulfilment of the requirements for the degree
MSc (Agric): Animal Science (Animal Nutrition)
In the Faculty of Natural and Agricultural Sciences
University of Pretoria

Supervisor: Prof. L.J. Erasmus
Co-supervisor: Prof. R. Meeske

November 2013

TABLE OF CONTENTS

DECLARATION

I declare that this dissertation for the degree MSc (Agric): Animal Science (Animal Nutrition) at the University of Pretoria has not been submitted for a degree at any other university. 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 the University of Pretoria 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.

…….. ……..

ACKNOWLEDGEMENTS

I would like to use this opportunity to thank the following people for their contribution and support to this study. Without you none of this would have been possible.

I want to start off by thanking my wife, Saretha van Wyngaard, for all her loving support and patience from day one of undertaking this MSc. This includes us moving down to George with the ever uncertainty of this being permanent or temporary, but with my wife by my side we made it a great success.

My parents, Charles and Renee van Wyngaard, for their motivational and financial support to undertake this MSc even though it meant that my father had to work twice as hard to organize all the paraphernalia at the Plot.

Professor Lourens Erasmus, one of my supervisors, for selecting me as one of his students and granting me the opportunity to do this study at the Outeniqua Research Farm. Furthermore for all the support and advice during the theoretical part of the MSc.

Professor Robin Meeske, my other supervisor, for undertaking me as one of his students and for all his advice, support and contributions throughout this study. Furthermore for being always available if one has a question not only regarding the study, for the motivational and reassuring effect that he has on you prior a platform presentation and lastly for the routine table tennis during lunchtime.

Western Cape Agricultural Research Trust for the bursary they have granted me for the duration of this study and for being the main financial support to make this study possible. Also for making the Trust cows available for research and for all the support in making the Outeniqua Research Farm a successful dairy farm. It was a privilege to work at the Outeniqua Research Farm.

Western Cape Department of Agriculture for permitting and supporting this study for research resolutions.

Lobke Steyn for supporting me with all the rumen samples taken during my study and for having a good laugh or two while doing it. And for teaching me all the important wiles to conquer Microsoft Word. I would also like to thank her for her friendship.

Pieter Swanepoel, who was always willing to help before even knowing what he was in for. I would also like to thank him for his invaluable friendship, contagious happiness and lastly for the routine table tennis during lunchtime.

Ilze Fourie for keeping the order in the student centre and to ensure that all the Cake-club members receive cake on Cake day, furthermore for sharing all the finer details of finding what and where at the Outeniqua Research Farm.

Mr Gerrit van der Merwe for his invaluable knowledge of the dairy industry. His love for the Outeniqua Jersey herd was contagious. I would also like to thank him for advising which cows to use in the study, for doing the body condition scoring of the test cows, for doing all the inseminations, for helping with the weighing of the cows, for all the historical stories and lastly for the routine table tennis during lunchtime.

Pieter Cronje, Pieter du Plessis and Hennie Gerber for their help with the infrastructure, maintenance and organisation of this study. I would also like to thank Pieter Cronje and Pieter du Plessis for their weekend duties, to ensure that everything ran smoothly and to do the odd insemination or two.

Doctor Philip Botha for all the moral support during the study and for always being there if help is needed, furthermore I would like to thank him for all the hilariously funny teatime stories and lastly for the competitive routine table tennis during lunchtime.

Janke van der Colf for lending an ear for all the pasture and Microsoft Word related questions.

Milking team, Sina Smit, Mercia Wildschut and Emmerentia Petoors, for doing an excellent job milking my test cows early mornings and late afternoons, also for all the patience during milk sampling periods.

Jastin Smit for always having a positive attitude no matter what time the morning and for helping with endless tasks without me asking, furthermore for fetching my cows every morning and afternoon.

Daniël Veldman, thank you for your life lessons and rugby insight. What a pleasure it has been, furthermore for all the help in and out the milking parlour.

Abraham Wildschut for your ever presence and pointing a problem out before it happens.

Taitus Afrika for weighing out all 30 tons of my feed into 3 kilogram bags and for fetching my cows on weekends while on duty.

To the rest of the people who work at the Outeniqua Research Farm.

Elise Ferreira for all her support and help in the lab and for providing me with all the relevant protocols and procedures regarding the chemical feed analyses performed at the Nutrilab, University of Pretoria.

To the rest of the Nutrilab staff, especially Truida Smit, Gerde Kotze, Ilze and Tebogo that supported and helped me with the chemical feed analyses. They all were very welcoming and passionate in what they do.

Lactolab for all the milk component analyses and for the prompt results.

Nestlé for calculating the milk price of each treatment.

Bernard van der Merwe and NOVA feeds for mixing my feed and for delivering it in time.

Wilna Brink and staff at the Elsenburg library. Thank you for your support in finding references for me and for replying promptly.

To the rest that I did not mention, thank you.

SUMMARY

Effect of palm kernel expeller supplementation on production performance of Jersey cows grazing kikuyu/ryegrass pasture

J.D.V. van Wyngaard

Supervisor: Prof. L.J. Erasmus

Co-supervisor: Prof. R. Meeske

Department: Animal and Wildlife Sciences

Faculty: Natural and Agricultural Sciences

Degree: MSc (Agric): Animal Science (Animal Nutrition)

Ruminant feed supplements are price sensitive and are effected by the continuous fluctuation of other raw material feed prices. Therefore, improving the efficiency of production and reducing cost of supplement concentrates for dairy cows are becoming increasingly important both for the smallholder and commercial dairy farmer. This can be overcome by replacing expensive energy and protein feeds with cheaper by-products. During periods of high maize prices, replacing maize with lower cost high fibre by-products becomes an economically viable option. Palm kernel expeller (PKE) fits the profile of a low cost, high fibre by-product. The aim of this study was to determine the effect of different inclusion levels of PKE in dairy concentrates for Jersey cows on milk production, milk composition, body weight (BW) and body condition score (BCS) change, rumen parameters and *in situ* ruminal kikuyu/ryegrass pasture degradability of dry matter (DM_d) and neutral detergent fibre (NDF_d) as well as NDF_d rate (NDF k_d).

The study was conducted at the Outeniqua Research Farm situated near George in the Western Cape and cows grazed high quality kikuyu/ryegrass pasture during spring. Forty eight multiparous high producing Jersey cows were blocked according to 4% fat corrected milk (FCM), days in milk (DIM) and lactation number and randomly allocated to three treatments (control, low PKE, and high PKE). The PKE inclusion level in the control, low PKE, and high PKE treatment concentrates was 0, 20, and 40%, respectively. The PKE replaced part of the maize and protein sources in the concentrate. Milk yield was recorded daily and milk composition was determined in two week intervals over a 60 d period, after a 21 d adaptation period. Additionally, eight lactating rumen-fistulated cows were randomly allocated to the

control and high PKE treatment in a two period crossover design. Ruminal pH, volatile fatty acids (VFA's), ruminal ammonia-nitrogen (NH_3-N), and *in situ* ruminal kikuyu/ryegrass pasture DM_d, NDF_d and NDF k_d were measured. Cows received 6 kg (as is) concentrate per day divided over two milking periods and strip grazed kikuyu/ryegrass pasture as one group.

Milk yield and milk fat content did not differ ($P > 0.05$) between treatments and were 21.3, 21.3 and 20.7 kg/cow/d and 4.63, 4.65, and 4.66% for cows receiving the control, low PKE and high PKE treatments, respectively. Milk protein, milk urea nitrogen (MUN), BW and BCS did not differ ($P > 0.05$) between treatments. Total VFA's, average ruminal pH, ruminal NH_3-N, and *in situ* ruminal kikuyu/ryegrass pasture DM_d and NDF_d as well as NDF k_d did not differ ($P > 0.05$) between treatments. The acetic to propionic acid ratio was, however, higher ($P < 0.05$) for cows supplemented with the high PKE treatment.

It can be concluded that partial replacement of maize with 20 or 40% PKE in a lactating dairy cow concentrate did not affect milk yield, milk fat content, milk protein content, somatic cell count (SCC), BW, or BCS. Rumen fermentation was unaffected and a healthy rumen environment was sustained. The replacement of higher cost maize and soybean oilcake by a lower cost PKE decreased feed cost. It is however not recommended to include PKE at 40% in the concentrate due to the increased time spent by cows in the milking parlour and the low palatability of PKE, which could lead to the tendency of increased concentrate refusals. It can be extrapolated from the data obtained from this study that milk production will be sustained when PKE is fed to cows on pasture at 2.4 kg/cow/day.

OPSOMMING

Effek van gepersde palm-oliekoek (*palm kernel expeller)* supplementering op produksie prestasie van Jerseykoeie op kikoejoe/raaigras-weiding

J.D.V. van Wyngaard

Studieleier: Prof. L.J. Erasmus

Mede studieleier: Prof. R. Meeske

Departement: Vee- en Wildkunde

Fakulteit: Natuur- en Landbouwetenskappe

Graad: MSc (Agric): Veekunde (Dierevoeding)

Kragvoeraanvulling is prys sensitief en word geaffekteer deur die voortdurende wisseling van grondstofvoerpryse. Gevolglik is ‘n verhoging in die doeltreffendheid van melkproduksie en ‘n verlaging van kragvoeronkostes besig om al meer belangrik te word vir beide kommersiële en opkomende suiwelboere. ‘n Logiese strategie is om mielies met ‘n goedkoper, hoë vesel byproduk te vervang, wanneer die mielie prys hoog is. Gepersde palm-oliekoek (PKE) pas die profiel van ‘n goedkoper, hoë vesel byproduk. Die doel van die studie was om die effek van verskillende insluitingspeile van PKE in ‘n suiwelkragvoer, vir weidende Jerseykoeie gevoer, op melkproduksie, melksamestelling, liggaamsmassa (BW) en liggaamskondisietelling (BCS) verskil, rumenparameters, en *in situ* rumen kikoejoe/raaigras-degradeerbaarheid van droë-materiaal en NDF (DM_d en NDF_d, onderskeidelik) asook tempo van kikoejoe/raaigras-degradeerbaarheid van NDF (NDF k_d) te bepaal.

Die studie is uitgevoer op die Outeniqua Navorsingsplaas naby George, Wes-Kaap, gedurende die lente, waar suiwelkoeie kikoejoe/raaigras bewei het. Agt-en-veertig lakterende Jerseykoeie is geblok volgens 4% vet-gekorrigeerde melkopbrengs, dae-in-melk en laktasienommer. Koeie binne blokke is ewekansig aan een van drie behandelingsgroepe toegeken. Die drie behandelings was kragvoer met 0% PKE (kontrole), 20% PKE (lae PKE) en 40% PKE (hoë PKE) wat teen 6 kg (nat basis) per koei per dag versprei oor twee melkperiodes gevoer was. Gepersde palm-oliekoek het `n gedeelte van die mielies en die proteïenbron in die suiwelkragvoer vervang. Kikoejoe/raaigras-weiding is teen 10 kg DM per koei per dag toegeken en die weiding is as een groep strookbewei. Melkproduksie is op `n daaglikse basis en melksamestelling op `n twee-weeklikse interval bepaal oor `n

tydperk van 60 dae, na 21 dae aanpassing. Addisioneel is agt rumen-gekanuleerde Jerseykoeie, wat ewekansig aan die kontrole- en hoë PKE-behandelingsgroepe toegeken is, in `n omslag-ontwerp met twee behandelings en twee periodes gebruik. Rumen-pH, vlugtige vetsure (VFA), rumen-ammoniakstikstof (NH_3-N), en *in situ* rumen kikoejoe/raaigras DM_d, NDF_d, en NDF k_d is bepaal.

Melkproduksie en melkvetpersentasie het nie tussen behandelings verskil nie ($P > 0.05$) en was 21.3, 21.3 en 20.7 kg/koei/d, en 4.63, 4.65, en 4.66%, onderskeidelik, vir die kontrole, lae PKE en hoë PKE-behandelings. Melkproteïen, melk-ureum-stikstof (MUN), BW en BCS het nie ($P > 0.05$) tussen behandelings verskil nie. Totale VFA, gemiddelde rumen-pH, rumen-NH_3-N, en *in situ* rumen kikoejoe/raaigras DM_d, NDF_d en NDF k_d het nie ($P > 0.05$) tussen behandelings verskil nie. Die asetaat- tot propionsuurverhouding het egter verskil ($P < 0.05$).

Die gevolgtrekking kan gemaak word dat die gedeeltelike vervanging van mielies met 20 of 40% PKE in `n suiwelkragvoer nie die melkproduksie, melkvet, melkproteïen, somatiese-seltelling (SCC), BW of BCS beïnvloed het nie. Rumen-fermentasie is nie negatief deur PKE beïnvloed nie en `n gesonde rumen-omgewing is behou. Die vervanging van hoë koste mielies en sojaboon-oliekoek met `n lae koste PKE het die voerkoste verlaag. Dit is wel nie prakties om `n suiwelkragvoer met `n 40% PKE insluiting in die melkstal te voer nie weens die stadiger tempo van inname as gevolg van `n laer smaaklikheid. Die 40% PKE insluitingspeil het ook gelei tot meer kragvoer-reste in die melkstal.

Dit kan van die data in die studie afgelei word dat PKE vir suiwelkoeie op weiding gevoer kan word teen 2.4 kg/koei/d sonder dat melkproduksie verlaag.

LIST OF ABBREVIATIONS

° C	Degree Celsius
µm	Micrometre
AA	Amino acid
ADF	Acid detergent fibre
ADICP	Acid detergent insoluble crude protein
ADIN	Acid detergent insoluble nitrogen
AM	Morning
AOAC	Association of Official Analytical Chemists
AR	Annual ryegrass
ARC	Agricultural Research Council
BCS	Body condition score
BP	Beet pulp
BUN	Blood urea nitrogen
BW	Body weight
BWC	Body weight change
C	Control
Ca	Calcium
ca.	Approximately
CF	Crude fibre
cm	Centimetre
cm^2	Square centimetre
Co	Cobalt
CP	Crude protein
Cu	Copper
Cys	Cysteine
d	Day
DE	Digestible energy
DIM	Days in milk

dl	Decilitre
DM	Dry matter
DM_d	Dry matter degradability
DMI	Dry matter intake
E	East
ECM	Energy corrected milk
EE	Ether extract
F	Fibre-based
FCM	Fat corrected milk
Fe	Iron
g	Gram
GE	Gross energy
GHP	Hydrophilic polypropylene
h	Hour
H_2SO_4	Sulphuric acid
H_3PO_3	Ortho-phosphoric acid
ha	Hectare
HC	Hominy chop
I	Iodine
IU	International unit
IVOMD	*In vitro* organic matter digestibility
K	Potassium
K/AR	Kikuyu and annual ryegrass
kg	Kilogram
kPa	Kilopascal
L	Litre
LAN	Limestone ammonium nitrate
Lys	Lysine
m	Metre
m^2	Square metre

MAFF	Ministry of Agriculture, Fisheries and Food
Max	Maximum
Mb	Molybdenum
ME	Metabolisable energy
Met	Methionine
Mg	Magnesium
mg	Milligram
MgO	Magnesium oxide
Min	Minimum
MJ	Mega joule
ml	Millilitre
mm	Millimetre
Mn	Manganese
MUN	Milk urea nitrogen
N	Nitrogen
Na	Sodium
NDF k_d	Neutral detergent fibre degradability rate
NDF	Neutral detergent fibre
NDF_d	Neutral detergent fibre degradability
NFC	Non fibre carbohydrate
NH_3-N	Ammonia-nitrogen
NRC	National Research Council
OG	Orchard grass
OMD	Organic matter digestibility
P	Phosphorus
PA	Pasture allowance
peNDF	Physically effective neutral detergent fibre
pH	Negative logarithm to the base ten of the hydrogen ion concentration in the solution
PKC	Palm kernel cake
PKE	Palm kernel expeller

PKM	Palm kernel meal
PM	Afternoon
ppm	Parts per million
PR	Perennial ryegrass
R	South African Rand
RFC	Readily fermentable carbohydrates
rpm	Revolutions per minute
RPM	Rising plate meter
RSA	Republic of South Africa
RUP	Rumen undegradable protein
S	Starch-based or South or Sulphur
SCC	Somatic cell count
Se	Selenium
SEM	Standard error of mean
SEPKC	Solvent extracted palm kernel cake
SF	Low fibre/starch-based
SH	Soybean hulls
SR	Substitution rate
t	Ton
T/FG	Perennial timothy and meadow fescue grass
Thr	Threonine
TMR	Total mix ration
Trp	Tryptophan
VFA	Volatile fatty acid
vs.	*Versus*
yr	Year
Zn	Zinc

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

Introduction

The number of milk producers in South Africa has decreased by 36% from January 2007 to January 2012 (Coetzee, 2012). The Western-Cape has the highest number of milk producers and producer-distributors, as well as the second highest number of milk buyers compared to the other provinces of South Africa (Coetzee, 2012). This decrease in milk producers puts pressure on the prevailing milk producers to satisfy the ever increasing demand for milk and milk products. Low milk prices and increased input costs amplify the financial pressure experienced by today's dairy farmer, not even mentioning the demand of lowering their carbon footprint.

Improving the efficiency of production and reducing the cost of concentrate supplements for dairy cows are becoming increasingly important for the dairy farmer. Dairy concentrates contribute up to 66% of the total feed cost in pasture grazing systems according to Meeske *et al.* (2006). High maize and oilcake prices have a substantial impact on milk production costs. Maize grain can constitute up to 70 to 80% of a conventional dairy concentrate and soybean oilcake can constitute up to 8 to 12% of the concentrate (Meeske *et al.*, 2009), both of these feed sources are expensive. The current cost of maize is R2 580/t and that of soybean oilcake is R4 400/t. When the maize price is high, replacing maize with lower cost high fibre by-products becomes an economically viable option.

In a study previously conducted at the Outeniqua Research Farm it was shown that maize, in the concentrate supplement of dairy cows, can be replaced by high fibre by-products such as hominy chop, gluten 20 and bran without causing a reduction in milk production and actually resulting in an increase in milk fat content (Lingnau, 2011). Input cost can be significantly reduced by replacing a starch-based concentrate with a fibre-based concentrate (Muller *et al.,* 2001). A fibre-based concentrate also results in an increase in pasture intake and total dry matter intake (DMI) (Meijs, 1986; Sayers, 1999) and is able to sustain or even increase milk production and milk fat percentages for dairy cows grazing ryegrass pasture (Meijs, 1986; Sayers, 1999; Delahoy *et al.*, 2003).

Palm kernel expeller is a low cost, high fibre residue or by-product from the palm kernel oil extraction process of the African Palm seed (Abdullah & Hutagalung, 1988; Carvalho *et al.*, 2006; Chanjula *et al.*, 2011). The African Palm seed is produced mainly from three equatorial tropics; South-East Asia, South America and Africa. The neutral detergent fibre (NDF) content of PKE is high (range: 66.4 – 80.1% of DM) and is therefore regarded as a high fibre by-product. The crude protein (CP) content of PKE ranges from 14.2 to 19.6% DM (literature review) which is higher than that of maize grain (*ca.* average of 9.8% DM; McDonald *et al.*, 2002). Most of the energy from PKE comes from the oil and NDF fraction. As PKE is very low in starch and sugars, this lowers the risk of developing acidosis and other rumen health disorders (Varga *et al.*, 1998). Palm kernel expeller is invaluable in supplying protein to ruminants, and most of the common minerals are within the acceptable ranges (Alimon, 2004). According to Zahari & Alimon (2003) PKE is used as a source of energy and fibre for dairy cows at inclusion levels of 30 – 50% of the total diet, however Carvalho *et al.* (2006) states that PKE is generally included in small amounts (< 10%) in dairy concentrates due to its low palatability. Palm kernel expeller is mainly used as a pasture extender in Australia and New Zealand when pasture growth rate is low.

Final recommendations on inclusion levels cannot be made, because the number of studies in which fibre-based concentrates replaced starch-based concentrates is limited and half of the studies were conducted in confinement (Bargo *et al.*, 2003). The optimal use of PKE as supplement to cows on pasture systems in the Eastern and Southern Cape needs to be determined.

The aim of this study was to determine the effect of partially replacing maize with PKE in concentrates for dairy cows on milk production, milk composition, BW and BCS of cows grazing kikuyu/ryegrass pasture during spring. In addition, rumen-fistulated cows were used to determine the effect of PKE supplementation on rumen fermentation patterns.

CHAPTER 2

Literature review

2.1 Introduction

The nutrient requirements of high-producing dairy cows cannot be satisfied by only grazing high quality pastures (Dixon & Stockdale, 1999). Allen (2000) stated that it is well known that energy supply is the first limiting factor for increasing the productivity of lactating dairy cows. Supplements can bridge the nutrient gap, but at the cost of pasture DMI (Minson, 1991). Supplements are also price sensitive and are effected by the continuous fluctuation of raw material feed prices. Therefore improving the efficiency of production and reducing cost of supplement concentrates for dairy cows are becoming increasingly important both for the small holder and commercial dairy farmer. High maize and oilcake prizes have a substantial impact on production cost to produce milk. Maize grain can constitute up to 70 to 80% of a conventional dairy concentrate and soybean oilcake can constitute up to 8 to 12% of the concentrate (Meeske *et al.*, 2009). According to Meeske *et al*. (2006) dairy concentrates contribute up to 66% of the total feed cost in pasture grazing systems. Therefore expensive energy and protein sources are subject to replacement by cheaper by-products.

High fibre by-products can maintain a high ruminal pH, enhance pasture digestion and hence result in increased DMI (Bargo *et al.*, 2003). Bradford & Mullins (2012) stated that the replacement of grain with a non-forage fibre source is profitable in some scenarios and often increases DMI. Palm kernel expeller is a by-product from the palm-oil industry and has been extensively used in the Asian regions as a feed source for goats and other animals. Palm kernel expeller could be used as feedstuff for ruminants, especially for dairy cows due to the fibrous nature of PKE (Abdullah *et al.*, 1995). According to MAFF (1992) PKE is considered as a medium quality energy feed with a moderate content of CP. The majority of studies regarding PKE on animal production were targeted on goats and beef cattle. Therefore, further research on the use of PKE in grazing dairy cows is justified.

In this review the value of kikuyu/ryegrass pastures will be discussed as well as the effect of high fibrous concentrates *vs.* starch concentrates and PKE on the performance of lactating dairy cows.

2.2 Kikuyu/ryegrass pasture

2.2.1 Kikuyu morphology

Pennisetum clandestinum (Kikuyu) is a perennial tropical pasture species and possesses a C4 photosynthetic pathway. This grass species is robust and creeps vigorously using rhizomes (below soil) and stolons (above soil) (Dickinson *et al.*, 2004). The dairy farms in the Southern Cape of South Africa are dominated by irrigated kikuyu pastures during the summer and autumn months when kikuyu is most active (Botha *et al.*, 2008b). However, kikuyu is dormant during late winter and early spring (August and September) in the Southern Cape (Botha, 2003). Kikuyu supports high stocking rates and milk production per hectare, only when well managed (Reeves, 1997). However, the nutrient value of kikuyu is low when compared to temperate pasture species, as such milk production per cow is also low (Marais, 2001). Therefore, cows principally grazing kikuyu-only pastures should be supplemented to overcome the nutrient shortages implemented by kikuyu-only pastures. However, supplementation increases the total feed cost with marginal improvements if not implemented correctly. Therefore, Botha *et al.* (2008a) suggested a strategy to incorporate legumes or other grasses into kikuyu-based pasture systems to increase the seasonal dry matter (DM) production and quality of the pasture.

2.2.2 Ryegrass morphology

Lolium multiflorum (annual ryegrass) is a temperate grass species or cool season grass, which is most active in the winter months (June, July and early August). Annual ryegrass has a higher metabolisable energy (ME) (*ca.* 1 MJ/kg DM) compared to kikuyu (Fulkerson *et al.*, 2006). Therefore, annual ryegrass would be a good candidate to be incorporated into kikuyu-only pastures. The nutritive value of annual ryegrass during the spring as obtained by previous authors is summarized in Table 2.1. The specific ryegrass cultivar, *Lolium multiflorum* Lam. (Italian ryegrass), has higher growth rates during winter and early spring when compared to perennial

ryegrasses, as such Italian ryegrass contributes more to fodder flow systems in mid-July to September compared to perennial ryegrasses (Thom & Prestidge, 1996). Lowe *et al.* (1999) stated that Italian ryegrass is invaluable in terms of herbage yield and milk production per cow per hectare when irrigated accordingly. According to Botha *et al.* (2008a) when annual ryegrass was incorporated into kikuyu pasture the seasonal fodder availability changed and the spring DM production increased. Botha *et al.* (2008b) found that kikuyu/ryegrass pasture delivered a more uniform seasonal fodder availability compared to that of kikuyu-only and kikuyu-clover pasture, thereby resulting in a reduced amount of variation in grazing capacity and milk production.

2.2.3 Grazing management

According to Reeves *et al.* (1996a) the optimum time to graze ryegrass is when the plant is in its 3-leaf stage of growth. Fulkerson & Slack (1994) reported that when grazing intervals surpasses this a decrease in herbage quality is expected due to leaf senescence and that shorter grazing intervals will lead to depleted plant reserves which in return will decrease regrowth after defoliation. Stockdale (2000) stated that correct pasture allocation is of immense importance as under-utilization of pasture will affect pasture quality and over-utilization of pasture impedes pasture regrowth. Stockdale (2000) found that pasture should be grazed at a stubble height of 5 to 6 cm to ensure optimal pasture regrowth and quality. Abrahamse *et al.* (2008) found that pasture DMI can be increased by increasing the pasture allocation frequency from once every four days to once a day, especially when the allocated pasture was high. Therefore the allocation of a new strip of pasture two times a day could be even more advantageous.

Table 2.1 Comparative nutrient composition and nitrogen application of annual ryegrass during spring

Author	N[1] application (kg N/ha)	Nutrient composition[2] (g/kg DM or as stated)										
		DM	Ash	NDF	ADF	ADL	CP	EE	ME[4]	IVOMD	Ca	P	Starch
Fulkerson *et al.* (1998)	-	-	-	-	-	-	251	-	-	-	5.9	3.1	-
Dalley *et al.* (1999)	-	-	-	-	-	-	-	-	-	-	5.9	3.1	-
Lowe *et al.* (1999)	-	-	-	462	276	-	255	-	9.5	-	-	-	-
Fulkerson *et al.* (2006)	-	-	-	444	221	-	220	-	11.3	-	-	-	-
Meeske *et al.* (2006)	-	147	871	490	280	-	180	-	10.9	-	6.7	3.6	-
Fulkerson *et al.* (2007)	-	-	-	531	274	-	247	-	9.7	-	-	-	-
Lehmann *et al.* (2007)	56 (LAN)[3]	-	129	444	-	-	251	-	11.3	-	5.0	5.0	-
Botha *et al.* (2008a)	-	-	-	501	-	-	218	-	11.3	-	4.7	4.8	-
Malleson (2008)	56 (LAN)	137	132	452	260	-	265	32	11.3	802	5.2	4.1	2.0
Erasmus (2009)	55 (LAN)	127	114	459	270	-	227	34	10.9	-	4.1	3.9	-
Coetzee (2011)	56 (LAN)	155	-	512	305	-	233	34	10.8	761	4.0	3.7	-
Lingnau (2011)	56 (LAN)	147	135	541	261	80	259	45	11.4	846	-	-	-
Van der Colf (2011)	-	-	-	454	-	-	241	-	11.7	756	-	-	-
Steyn (2012)	42 (LAN)	138	-	413	242	26	238	25	12.3	826	-	-	-

[1]N – nitrogen applied after each grazing
[2]DM – dry matter; NDF – neutral detergent fibre; ADF – acid detergent fibre; ADL – acid detergent lignin; CP – crude protein; EE – ether extract; ME – metabolisable energy; IVOMD – *in vitro* organic matter digestibility; Ca – calcium; P – phosphorus
[3]LAN – limestone ammonium nitrate
[4]MJ/kg DM

2.2.4 Estimating pasture intake

Pasture intake can be estimated by using direct or indirect methods. Direct methods may ensure more accurate results. However, these methods are intensely laborious, invasive to the animal, time consuming and costly. Indirect methods have been developed to overcome the disadvantages of direct methods. Kellaway *et al.* (1993) stated that indirect pasture-based techniques are based on the amount of pasture available before and after grazing. The rising plate meter (RPM) is a measuring instrument based on the Ellinbank pasture meter that was earlier developed by Earle & MacGowan (1979). The RPM manually records herbage stubble height in 5 mm increments (Sanderson *et al.*, 2001). It is well documented that the use of the RPM to determine pasture intake is inaccurate (Reeves *et al.*, 1996b; Malleson, 2008). Bargo *et al.* (2003) stated that group DMI estimations instead of individual estimations are the leading shortcoming of pasture-based techniques. Short grazing periods increases the reliability of the RPM (Smith *et al.*, 2005a) and it is of utmost importance to use a calculated regression that refers directly to the specific area, specific pasture and specific season to increase the accuracy of the RPM (Sanderson *et al.*, 2001). Stockdale (1984) found that the use of separate regressions for pre- and post-grazing has yielded higher accuracies.

2.3 Supplementation on pasture-based systems

According to Stockdale (2000) and Peyraud & Delaby (2001) the ultimate purpose of supplementation for dairy cows at pasture is to overcome the relative low total DMI and energy intake of pasture-only diets. This will sustain higher levels of milk production and will optimize profit per cow, hence optimizing the profit per unit of land (Fales *et al.*, 1995). Dixon & Stockdale (1999) also states that the nutrient requirements of high-producing dairy cows cannot be satisfied by only grazing high quality pastures. This is because the main limiting factor for milk production on high quality ryegrass pasture is energy intake and not metabolisable protein (Fulkerson *et al.*, 1998; Kolver & Muller, 1998). Kellaway & Porta (1993) suggested the following intentions for supplementation: increased milk production per cow, increased stocking rate and milk production per unit of land, improved pasture use with the higher stocking rate, sustained or improved body condition score to improved

reproduction during pasture shortage, and lastly increased milk protein content by energy supplementation.

Feeding energy supplements when there is abundant forage available for grazing, increases the total food intake while reducing pasture intake (Minson, 1991). This is a result of cows substituting the supplement for part of the pasture they would have consumed (Stockdale, 2000). Supplements usually decrease the DMI of pastures (Minson, 1991), which is defined as substitution (Bargo *et al.*, 2003). The substitution rate (SR) is positively correlated with level of concentrate fed. Stockdale (2000) reported that SR and animal performance are affected by the type of supplement. It is also suggested that SR is affected by negative associative effects as ascribed by Dixon & Stockdale (1999), or by a reduction in grazing time as ascribed by McGilloway & Mayne (1996).

According to Dixon & Stockdale, (1999), there are two major factors that constrain the use of grain for lactating dairy cattle; the reduction in milk fat percentage due to excessive intake of readily fermentable carbohydrates (RFC), and the high RFC and low fibre values of high quality forage usually used for grazing dairy cows. Volatile fatty acids (VFA) that are produced in excess due to increased RFC, decreases the ruminal pH by unsettling the buffering capacity of cows resulting in a reduction in fibre digestion (Ranathunga *et al.*, 2010). As DMI of pasture decreases due to substitution, less effective fibre is taken in resulting in less rumination and saliva secretion. As a result, a decrease in appetite, fibre digestion, ruminal microbial population and milk fat percentage may occur due to the lower ruminal pH (Kalscheur *et al.*, 1997).

2.4 Fibre-based *vs.* starch-based concentrate

2.4.1 Effect on ruminal parameters

The number of studies reporting the effect of fibre-based concentrate replacing starch-based concentrate on ruminal parameters, such as pH, NH_3-N and VFA's of grazing cows (not in confinement) are limited. These studies are represented in Table 2.2.

2.4.1.1 Ruminal pH

None of the authors in Table 2.2 reported any differences in ruminal pH between starch-based and fibre-based concentrates ($P > 0.05$).

Hoover (1986) stated that it is of utmost importance to maintain ruminal pH within a narrow range to ensure optimal ruminal fibre digestion. However, there is a discrepancy between the recommended pH levels for ruminal fibre digestion in the literature review. Dixon & Stockdale (1999) suggested that the optimal pH range for ruminal fibre digestion is 6.6 to 7.0, whereas Pitt *et al.* (1996) and Kolver *et al.* (1998a) suggested a range of 6.0 to 6.9 that stimulates optimal ruminal fibre digestion. The majority of previous authors reported that ruminal fibre digestion is rigorously inhibited when ruminal pH drops below 6.0 (Hoover, 1986; Sutton *et al.*, 1986; Dixon & Stockdale, 1999). Acute and subacute ruminal acidosis, based on the mean and minimum pH values, are defined by a pH below 5 and below 5.6, respectively (Owens *et al.*, 1996). AlZahal *et al.* (2007) proposed a threshold of 475 min below a pH of 5.8 is an indication of subacute ruminal acidosis. Complete cessation of ruminal fibre digestion occurs when pH drops below 5.0 (Mould *et al.*, 1984).

The range of the ruminal pH is not the only factor that affects ruminal fibre digestion. According to Ørskov & Istasse (1983) the extent of pH depression and the time that pH remained below 6.0 should also be considered in affecting ruminal fibre digestion. This is supported by Beauchemin & Rode (1999) who also added that a perpetual low pH is needed to decrease ruminal fibre digestion and Mertens (1979) reported that extreme daily variation in ruminal pH can be just as harmful to ruminal microbes, due to constant metabolic alterations by ruminal microbes. The drop in pH, post concentrate feeding, is as a result of the presence of RFC in the concentrates (Dixon & Stockdale, 1999), as such starch fermentability in the rumen has a more pronounced effect on ruminal pH than that of the physical characteristics of feedstuffs (Yang *et al.*, 2001). Bargo *et al.* (2002b) reported that the ruminal pH is the highest before concentrate feeding and lowest after concentrate feeding, more specifically 2 to 5 h post concentrate feeding (Nordlund & Garrett, 1994; Nocek, 1997; Cajarville *et al.*, 2006). Colman *et al.* (2010) stated that pH varies considerably at different locations in the rumen and during the day. Therefore, pH values from different studies should be compared with caution.

2.4.1.2 Volatile fatty acid profile

Supplementation had no effect on total VFA concentration of grazing cows when starch-based concentrates were replaced by fibre-based concentrates ($P > 0.05$) (Van Vuuren *et al.*, 1986; Khalili & Sairanen, 2000; Sayers *et al.*, 2003), regardless to rumen pH reductions (Carruthers & Neil, 1997; Carruthers *et al.*, 1997). This is supported by Seymour *et al.* (2005) that found that rumen pH is negatively related to total VFA concentration in rumen fluid. Bargo *et al.* (2003) reviewed a total of ten studies, where grazing cows received energy supplementation, and compiled a mean total VFA concentration of 120.9 mmol/L with a range of 90.3 to 151.4 120.9 mmol/L. Sayers *et al.* (2003) found that fibre-based concentrates increased the concentrations of acetate and butyrate, and decreased the concentration of propionate ($P < 0.05$), whereas Khalili & Sairanen (2000) reported no change in the principle VFA's ($P > 0.05$). Lingnau (2011) also reported that the fibre-based concentrate decreased the propionate concentrate ($P < 0.05$), but reported the opposite of Sayers *et al.* (2003) regarding the acetate and butyrate concentrations. The decrease in ruminal propionate concentrations observed when fibre-based concentrates are fed could be related to increased fibre and decreased non-structural carbohydrates in the diet of grazing dairy cows.

Acetic, propionic and butyric acid are the three principle VFA's of the rumen (Seymour *et al.*, 2005), whereas acetic acid being the dominant VFA in the rumen of cows (Ishler *et al.*, 1996). Bach *et al.* (1999) found that the acetate proportion increased in response to increased fibre intake, whereas Zebeli *et al.* (2008b) reported that the acetate proportion responded negatively to increased non-structural carbohydrate intake. Kolver *et al.* (1998b) found that neither the total VFA, acetate or propionate concentration is affected by timing of supplementation. Gorosito *et al.* (1985) stated that valeric acid and *iso*-acids are required in small quantities for growth of cellulolytic microbes and that cellulose digestion was improved by adding these VFA's to cultures of rumen microbes.

2.4.1.3 Ruminal ammonia nitrogen profile

Van Vuuren *et al.* (1986) and Sayers *et al.* (2003) found no differences in ruminal NH_3-N when a fibre-based concentrate replaced a starch-based concentrate ($P > 0.05$). However, both Khalili & Sairanen (2000) and Lingnau (2011) reported decreased ruminal NH_3-N for the fibre-based concentrate compared to the starch-

based concentrate ($P < 0.05$). Bargo *et al.* (2003) reviewed a total of ten studies, where grazing cows received energy supplementation, and compiled a mean ruminal NH_3-N of 18.3 mg/dl (range: 8.7 to 32.2 mg/dl).

Free ruminal NH_3 is utilized by rumen microorganisms for synthesis of protein for microbial growth and fermentation of feeds for energy (Hoover, 1986). The ruminal NH_3-N values reported in Table 2.2 are well above 5 mg/dl which is the minimum NH_3-N concentration for maximum microbial protein synthesis as stated by Satter and Slyter (1974). The optimum ruminal NH_3-N range for improving microbial protein synthesis, digestibility and feed intake range are from 8.5 to 30 mg/dl McDonald *et al.* (2002). Hoover (1986), however, stated that maximum cellulose digestion is achieved when ruminal NH_3-N concentrations reach *ca.* 43 mg/dl. Erdman *et al.* (1986) found that the ruminal NH_3-N was at its lowest when ruminal DM or organic matter digestibility (OMD) was at its lowest. Erdman *et al.* (1986) also stated that when the dietary CP was equal or less than 6%, the optimum ruminal NH_3-N associated with microbial growth or nutrient digestion was 21.4 mg/dl compared to 6.2 mg/dl when the dietary CP was above 6%.

According to Bargo *et al.* (2002b) there are two daily peaks of ruminal NH_3-N concentration corresponding to ingestion of high CP pasture after receiving concentrate. This is in agreement with Cajarville *et al.* (2006) who found that the maximum NH_3-N concentration occurs at the minimum ruminal pH. Kolver *et al.* (1998b) found that when concentrate was fed to grazing cows synchronously with pasture rather than 4 h after pasture was fed, the maximum ruminal NH_3-N decreased by 33%. The effects of NH_3-N concentration are feed-dependent, as such minimum NH_3-N requirements are dependent on feed fermentability and the rate of growth of bacteria (Erdman *et al.*, 1986). Therefore generalized NH_3-N concentration ranges specified for optimal microbial growth or activity should be used with caution.

2.4.1.4 Pasture *in situ* degradability

Sayers *et al.* (2003) found that a starch-based or fibre-based concentrate did not affect the rate or extent of degradation of DM or CP of ryegrass ($P > 0.05$). Lingnau (2011) also found no effect on *in situ* ruminal digestion of ryegrass by replacing a starch-based concentrate with a fibre-based concentrate ($P > 0.05$).

Bargo *et al.* (2002a) stated that the rate of pasture DM and NDF degradation decreased, 6.8 *vs.* 5.4 %/h and 5.1 *vs.* 4.1 %/h respectively, when pasture-only treatments were supplemented with concentrate, with no effect on lag time, soluble fraction or insoluble potentially degradable fraction of DM or NDF. Beauchemin (1991) found that an increase in fibre concentration in the diet resulted in an increase in microbial digestion of forage *in sacco*, as indicated by a greater extent of DM and NDF disappearance and an increased rate of DM disappearance. Reis & Combs (2000) and Bargo *et al.* (2002a), however, found that the degradation rate of pasture was decreased only when high levels (>8 kg DM/d) of corn-based concentrates were fed to cows. Cajarville *et al.* (2006) supports this and stated that only the quantity and fermentation rate of a supplement can affect the utilization efficiency and degradability of forage. Beauchemin (1991) reported that the enhancement of ruminal forage digestion may also be related to increased pH of ruminal fluid which improves the rumen conditions for cellulolytic microorganisms to thrive.

Table 2.2 A summary of the effect of starch-based or fibre-based concentrate on ruminal parameters of grazing dairy cows

Reference	Cow Breed	Pasture[1]		Concentrate[2]		pH	NH_3-N[3] mg/dl	VFA[4] mmol/L				
		Type	PA	Type	Intake kg DM/d			Total	Acetate	Propionate	Butyrate	A:P[5]
Van Vuuren *et al.*, 1986	-	PR	-	S (maize/tapioca)	5.4	5.90	22.1	127.0	-	-	-	-
				F (BP)	5.2	5.90	20.4	130.0	-	-	-	-
Khalili & Sairanen, 2000	Holstein-Friesian	T/FG	40	S (barley)	4	6.17	32.2[a]	127.0	81.4	24.3	15.9	-
				F (oats/BP)	4	6.01	21.8[b]	132.0	84.5	27.1	15.3	-
Sayers *et al.*, 2003	-	PR	23	S (barley/wheat/corn)	5 to 10	5.80	12.00	121.6	68.1[a]	31.6[a]	17[a]	2.26[a]
				F (BP/citrus pulp)	5 to 10	5.96	13.60	122.5	73.5[b]	25.7[b]	18.4[b]	2.94[b]
Lingnau, 2011[6]	Jersey	K/AR	-	S (maize)	6.0	6.05	21.2[a]	122.0[a]	87.7[a]	19[a]	11.9[a]	4.90
				F (HC(35%)/wheat bran(18%))	6.0	6.08	18.8[b]	113.0[b]	82.6[b]	17.3[b]	10.4[b]	4.99

[1]PR – perennial ryegrass (*Lolium perenne*); T/FG - perennial timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) grass; K/AR – kikuyu (*Pennisetum clandestinum*) and annual ryegrass (*Lolium multiflorum*); PA – pasture allowance (kg DM/d)
[2]S – starch-based; F – fibre-based; BP – beet pulp; HC – hominy chop
[3]NH_3-N – ammonia-nitrogen
[4]VFA – volatile fatty acid
[5]A:P – acetate to propionate ratio
[6]Concentrate level on 'as is' basis
[a,b] means in the same column with different superscripts differ ($P < 0.05$)

2.4.2 Effect on production responses

Results from studies investigating the effect of fibre-based concentrate replacing starch-based concentrate on milk yield, milk composition and BW of grazing cows that is not in confinement are represented in Table 2.3.

2.4.2.1 Milk yield

Dry matter intake difference is one of the major limitations for milk production in grazing systems (Smith *et al.*, 2005b), rather than energy content of pasture (Kolver & Muller, 1998). Increased DMI potential is one of the advantages that fibre-based concentrates have over starch-based concentrates (Gehman *et al.*, 2006). Studies done by Meijs (1986) and Sayers (2003) found that total DMI were increased by 0.7 and 0.8 kg/d, respectively, when a fibre-based concentrate replaced a starch-based concentrate. A review done by Bargo *et al.* (2003) where they summarized several studies stated that fibre-based concentrates marginally increased DMI by 0.13 kg/d (DMI response range: -0.7 to 1.4 kg/d) compared to starch-based studies. Bargo *et al.* (2003) suggested that the higher DMI observed when fibre-based concentrates are fed are due to increased ruminal pH and pasture digestion when starch-based concentrates are replaced with fibre-based concentrates.

Meijs (1986) and Khalili & Sairanen (2000) reported increased milk production ($P < 0.05$) when a fibre-based concentrate replaced a starch-based concentrate. However, the majority of previous grazing studies reported similar milk yields comparing fibre-based to starch-based concentrates ($P > 0.05$) (Delahoy *et al.*, 2003; Sayers *et al.*, 2003; Gehman *et al.*, 2006; Meeske *et al.*, 2009; Lingnau, 2011). A review done by Bargo *et al.* (2003) stated that the overall milk production reduced slightly (-0.46 kg/d) when starch-based concentrates are replaced by fibre-based concentrates with a broad milk response range of -2.6 to 1.3 kg/d. However, this summary of Bargo *et al.* (2003) cannot be blindly followed as a guideline on a grazing pasture system, as Bargo *et al.* (2003) included confinement studies in his summary. The ruminal VFA profile play a correspondingly important role in establishing milk yield. Seymour *et al.* (2005) found that milk yield is positively correlated with butyric acid concentrations in the rumen ($r = 0.69$) followed by propionic acid ($r = 0.49$).

2.4.2.2 Milk fat

The majority of the grazing studies reported no effect on milk fat percentage when fibre-based concentrates replaced starch-based concentrates ($P > 0.05$) (Meijs, 1986; Khalili & Sairanen, 2000; Delahoy *et al.*, 2003; Gehman *et al.*, 2006). However, three studies reported increased milk fat percentage when fibre-based concentrates replaced starch-based concentrates fed to dairy cows grazing ryegrass pasture ($P < 0.05$) (Sayers *et al.*, 2003; Meeske *et al.*, 2009; Lingnau, 2011).

Of all the milk solids, milk fat content is the most sensitive to nutritional manipulation (Stockdale *et al.*, 2003). According to Bradford & Mullins (2012) the NDF content of non-forage fibre sources have a small mean particle size, low lignin content and a high fibre digestibility, therefore resulting in a low physical effective NDF (peNDF) content. Zebeli *et al.* (2008a) stated that peNDF is strongly associated with milk fat yield and ruminal pH. This is enriched by Allen (1997) whom reported a positive relationship between ruminal pH and milk fat percentage. The acetic to propionic acid ratio found in the VFA profile of the rumen plays a correspondingly important role in establishing the milk fat value (Section 2.4.1.2). According to Sutton (1984) milk fat content responds negatively by 5 to 3 g/kg per unit decrease in the acetate to propionate ratio, with a similar response on average by 5 g/kg for every unit fall in the acetate plus butyrate to propionate ratio. According to a review done by Thomas and Chamberlain (1984) a rumen content rich in acetate and butyrate fermentation consistently increased milk fat yield, where a propionate rich rumen fermentation reduced milk fat yield. The acetic to propionic acid ratio in rumen fluid are positively correlated to milk fat content (g/kg) (Seymour *et al.*, 2005) and Erdman (1988) stated that an acetic to propionic acid ratio below 2:1 is often associated with milk fat depression.

2.4.2.3 Milk protein

Meijs (1986), Khalili & Sairanen (2000), Meeske *et al.* (2009) and Lingnau (2011) reported similar milk protein content from grazing cows supplemented with either starch-based or fibre-based concentrates ($P > 0.05$). However, Delahoy *et al.* (2003) and Gehman *et al.* (2006) reported lower milk protein values from grazing cows supplemented with fibre-based concentrates. A review done by Bargo *et al.* (2003) summarized that milk protein content was reduced by -0.06 percentage units with fibre-based concentrates compared with starch-based concentrates, with a milk

protein response range of -0.21 to 0.05 percentage units. However, Bargo *et al.* (2003) also reported that definite conclusions could not be made regarding starch-based *vs*. fibre-based concentrates supplemented to grazing cows due to the small number of studies that involve these comparisons.

DePeters & Cant (1992) stated that milk protein content is less sensitive to dietary changes than milk fat content. This is emphasized by Sutton (1989) who reported that milk protein can only be altered by a range of *ca.* 0.6 percentage units, whereas milk fat content can be altered over a wide range of *ca.* 3 percentage units. Tas *et al.* (2005) reported that milk protein can be stimulated by increased glucose and/or amino acid absorption in the small intestine, and by increased propionate production in the rumen. Jenkins & McGuire (2006) stated that when RFC are fed to cows; it is expected that cows will produce more milk protein due to increased propionate and microbial protein production.

2.4.2.4 Milk lactose and somatic cell count

Khalili & Sairanen (2000) reported a higher milk lactose yield for cows supplemented with barley (starch-based) than for cows supplemented with oats, wheat bran and beet pulp (fibre-based) ($P < 0.05$). However, this could possibly be attributable to increased milk yield ($P < 0.05$) reported by Khalili & Sairanen (2000), with no alteration in milk lactose percentage ($P > 0.05$).

A study done by Gibson (1989) found that the milk lactose average for Jersey cows is in the region of 4.7%. Welper & Freeman (1992) reported a milk lactose content range of 4.61 to 5.04% accumulated across six different dairy breeds, whereas the NRC (2001) reported a more specific milk lactose average of around 4.85%. Milk lactose percentage varies the least compared to other milk components, irrespective to cow breed or diet changes, due to the low coefficient of variation of milk lactose contents; as such variance in milk lactose contents are of no importance (Sutton, 1989; Kennelly & Glimm, 1998). Jenkins & McGuire (2006) supported this statement and added that milk lactose content change is a result of severe feeding situations. Milk lactose content can also be affected by change in SCC or udder health (Kitchen, 1981; Welper & Freeman, 1992).

Somatic cells consist of udder epithelial cells and leukocytes, and are sensitive to lactation number and udder irritation/injury (De Villiers *et al.*, 2000). Udder health

can be monitored by using SCC as an indicator. A SCC above 300 x 10^3 cells/ml milk is indicative of subclinical mastitis and considered to be abnormal, and should be kept below 500 x 10^3 cells/ml milk for human consumption (De Villiers *et al.*, 2000).

2.4.2.5 Milk urea nitrogen

A limited amount of grazing studies, replacing starch-based concentrate with fibre-based concentrate, reported MUN. Gehman *et al.* (2006) reported similar MUN values between the corn starch-based (10.05 mg/dl) and fibre-based (9.85 mg/dl) concentrate ($P > 0.05$), however MUN was the highest for the barley starch-based (11.43 mg/dl) concentrate ($P < 0.05$). On the contrary, Delahoy *et al.* (2003) fed a fibre-based concentrate in addition to a starch-based concentrate for grazing dairy cows and reported that the starch-based concentrate yielded a lower MUN than the fibre-based concentrate (14.9 and 15.4 mg/dl, respectively; $P < 0.05$). Previous grazing studies reported MUN values of supplemented cows to average 19 mg/dl with a range of 14.8 to 37.6 mg/dl (Khalili and Sairanen, 2000; Bargo *et al.*, 2002a; Delahoy *et al.*, 2003). This could be contributed to the high CP values of the pasture ingested.

Dairy herd nutrition can be improved by using MUN as an indicator to monitor the nutritional status of lactating dairy cows (Kohn, 2007). The relationship between MUN and dietary protein and energy has been investigated by various authors. DePeters & Ferguson (1992) stated that MUN and blood urea nitrogen (BUN) are positively related with ruminal NH_3 concentrations, as such MUN and BUN can be used as indicators of ruminal nitrogen (N) capture. Jonker *et al.* (1999) additional added that MUN and BUN have extensively been used as indicators for the protein status of animals, but only when energy is adequate in the diet (Kohn, 2007). Roseler *et al.* (1993) suggested that variation in MUN concentration is related to the protein to energy ratio of the diet consumed. A study done by Baker *et al.* (1995) found that MUN concentrations increased with high levels of ready degradable protein. Jersey cows have a lower MUN content compared to Holstein cows (Rodriguez *et al.*, 1997). Kohn (2007) suggested that these differences are due to several factors: milk yield, milk fat and protein content, N intake, and BW. There is a disparity in the recommended MUN concentration for dairy cows, however as time passed the recommended MUN concentration declined. This is due to more research done in optimising the amount of protein fed to high producing cows and in

the process reducing the amount of excess protein excreted in urine. A study done by Jonker *et al.* (1999) determined the target MUN concentrations for cows fed according to NRC (1989) recommendations (Figure 2.1). Kohn (2007) recommended overall MUN concentrations between 8 to 12 mg/dl under typical production conditions. However, this relative low range of MUN concentrations is characteristic to cows receiving TMR's and not to cows on a pasture-based system. Milk urea nitrogen concentrations are normally higher for cows on pasture-based systems as previously cited (Bargo *et al.* 2003).

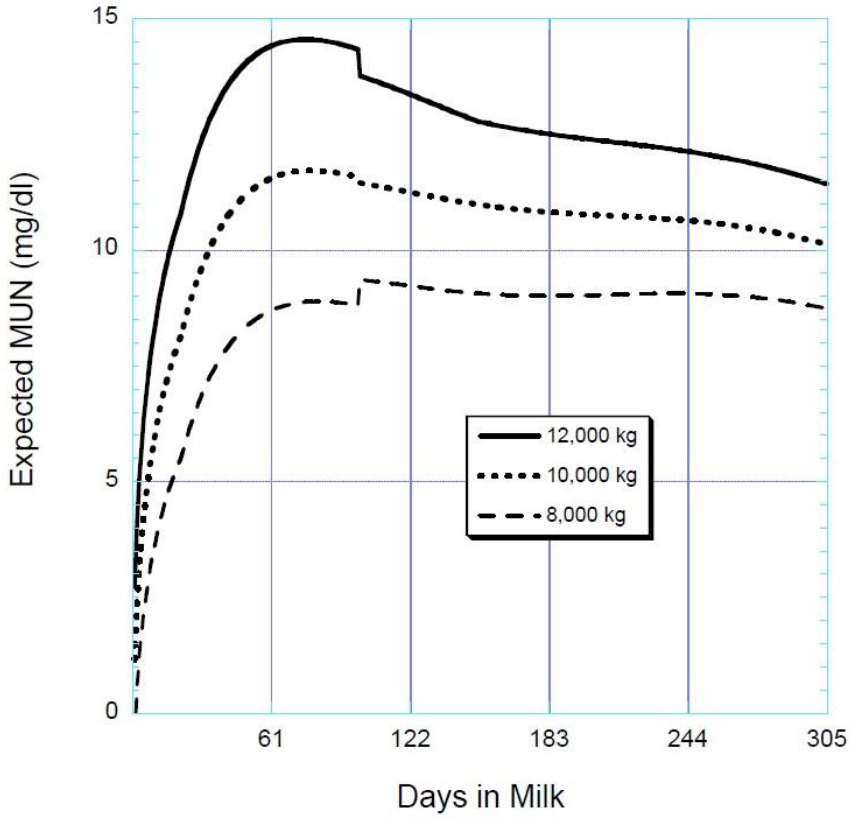

Figure 2.1 Predicted milk urea nitrogen (MUN, mg/dl) throughout a 305-day lactation for milk yield of 12,000 kg/lactation (———), 10,000 kg/lactation (.....) and 8,000 kg/lactation (- - - -) for cows fed according to NRC (1989) recommendations (Source: Jonker *et al.*, 1999; Kohn, 2007)

2.4.2.6 Body weight and body condition score

None of the authors cited in Table 2.3 reported any differences in BW change between starch-based and fibre-based concentrates (P > 0.05). Bargo *et al.* (2002a) stated that BW is not subject to change in such a short study period as would involve a feeding study.

Using only BW as indicator to determine body energy reserves could be erroneous, as BW varies between cow breeds. Gibb *et al.* (1992) emphasises this by reporting up to 40% variation in energy reserves in cows of the same weight. Roche *et al.* (2004) stated that body condition assessment has become an important tool in both research and farm management. The scoring system of Wildman *et al.* (1982), with a one to five scale focusing only on appearance and palpation of back and hind quarters, is the method more generally used to determine body condition score of cows. However, these methods are performed subjectively and the accuracy of the system is dependent on the scorer's competency and experience.

Table 2.3 A summary of the effect of starch-based or fibre-based concentrate on milk production parameters and body weight of grazing dairy cows

Author	Cow[1]			Pasture[2]		Concentrate		Milk yield kg/d	Milk composition			BWC[5] kg/d
	Breed	DIM	Milk	Type	PA	Type[3]	Intake kg DM/d		Fat g/kg	Protein g/kg	MUN[5] mg/dl	
Meijs, 1986	Dutch-Friesian	60	28.9	PR	28**	S (cassava/corn)	5.5	25.6[a]	39.6	34.0	-	0.28
						F (BP/SH/PKE)	5.4	26.9[b]	41.0	33.7	-	0.11
Van Vuuren *et al.*, 1986	-	-	-	PR	-	S (maize/tapioca)	0.8	19.3	41.0	33.0	-	-
						S (maize/tapioca)	5.4	20.0	38.0	33.0	-	-
						F (BP)	5.2	18.9	41.0	33.0	-	-
Khalili & Sairanen, 2000	Holstein Friesian	171	-	T/FG	40	C (pasture only)	0	18.4[a]	41.2[a]	34.2	40.0[a]	-
						S (barley)	4	19.7[b]	38.5[b]	34.2	36.3[b]	-
						F (oats/BP)	4	21[c]	37.6[b]	34.9	37.6[b]	-
Sayers *et al.*, 2003	-	40	41.5	PR	23	S (barley/wheat/corn)	5.0	33.3	37.5	33.5	-	-1.29
						F (BP/citrus pulp)	5.0	34.0	38.1	31.9	-	-0.99
						S (barley/wheat/corn)	10.0	37.3	30.8	34.4	-	-0.68
						F (BP/citrus pulp)	10.0	36.0	35.8	32.5	-	-0.83
Delahoy *et al.*, 2003	Holstein	182	33.5	OG	40	S (corn)	8.2	27.6	35.3	32.3[a]	14.9[a]	0.14
						F (BP/SH)	8.2	27.4	36.3	31.9[b]	15.4[b]	0.20
Gehman *et al.*, 2006	Holstein	130	41.1	AR	17	S (corn)	9.2	30.6	32.0	28.1[a]	10.1[a]	-0.05
						S (barley)	9.1	29.9	32.7	27.7[ab]	11.4[b]	-0.03
						F (citrus pulp)	9.2	30.0	32.6	27.0[b]	9.9[a]	-0.06
Meeske *et al.*, 2009[4]	Jersey	-	-	AR	-	S (maize)	6.0	21.0	36.6[a]	34.5	17.8	0.48
						SF (HC/wheat bran)	6.0	20.8	40.3[ab]	35.5	17.8	0.56
						F (HC/wheat bran)	6.0	20.1	44.1[b]	34.2	18.1	0.54
Lingnau, 2011[4]	Jersey	153	19.6	K/AR	-	S (maize)	6.0	19.9	40.7[a]	35.3	17.8	0.39
						SF (HC/wheat bran)	6.0	20.2	44.9[ab]	36.3	17.1	0.49
						F (HC/wheat bran)	6.0	19.0	47.5[b]	35.9	17.3	0.40

[1]Pre-experimental days in milk (DIM) and milk yield (kg/d)
[2]PR – perennial ryegrass (*Lolium perenne*); T/FG - perennial timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) grass; OG – orchardgrass (*Dactylis glomerata* L.); AR – annual ryegrass (*Lolium multiflorum*); K/AR – kikuyu (*Pennisetum clandestinum*) and annual ryegrass (*Lolium multiflorum*); PA – pasture allowance (kg DM/d); ** in kg OM/d
[3]S – starch-based; F – fibre-based; C – control; SF – low fibre/starch-based; BP – beet pulp; SH – soybean hulls; PKE – palm kernel expeller; HC – hominy chop
[4]Concentrate level on 'as is' basis
[5]MUN – milk urea nitrogen; BWC – body weight change
[a,b] means in the same column with different superscripts differ ($P < 0.05$)

2.4.3 Palm kernel expeller as a high fibre supplement

2.4.3.1 Origin

Palm kernel cake (PKC), also known as palm kernel meal (PKM), is a residue or by-product from the palm kernel oil extraction process of the African Palm seed (*Elaeis guineensis* Jacq.), representing more or less 50% of the original kernel (Crowther & Woodman, 1917; Abdullah & Hutagalung, 1988; Carvalho *et al.*, 2006; Chanjula *et al.*, 2011) and has long been recognised to be a significant ingredient in animal feed formulation (Collingwood, 1958). The African Palm comes from three main equatorial tropics; South-east Asia, South America and Africa. O`Mara *et al.* (1999) gives a detailed physiological description of the fruit and the kind of fruit preparations done before the oil extraction process commence. There is considerable variation in chemical composition of palm kernel by-products depending on the method of fat removal and the proportion of endocarp remaining (Jalaludin *et al.* 1991; Hindle *et al.*, 1995). Two types of PKC are commercially available, those where the oil is extracted by screw presses, termed palm kernel expeller (PKE; brown colour), or by solvent extraction, termed solvent extracted palm kernel cake (SEPKC; white grey colour) (O`Mara *et al.*, 1999). Palm kernel expeller has a higher percentage ether extract (EE) (5 – 12% of DM) compared to SEPKC (0.5 – 3.0% of DM) (Chin, 2001; Carvalho *et al.*, 2006). An additional difference between SEPKC and PKE is that SEPKC has a higher digestibility for most of the nutrient fractions compared to PKE except for the gross energy (GE) digestibility which is similar between the two feeds (O`Mara *et al.*, 1999). Therefore PKE has a higher digestible energy (DE) due to the higher GE value (O`Mara *et al.*, 1999).

2.4.3.2 Nutrient quality

The variation in nutrient composition of PKE can be seen in Table 2.4 as reported by several authors. Palm kernel expeller has a high nutritive value (O`Mara *et al.*, 1999) and can be classified as an energy feed due to a protein content of *ca.* 16 to 18%, therefore excluding it as a protein feed (Alimon, 2004). According to MAFF (1992) PKE is considered as a medium quality energy feed with a moderate content of CP. O`Mara *et al.* (1999) added that PKE is a moderate quality feed in terms of digestibility for ruminants (OMD<710 g/kg), but high in fibre, coarse and granular, and lowly palatable (Chanjula *et al.*, 2010). Alimon (2004) stated that PKE

has a similar nutrient composition compared to corn gluten or rice bran. The high NDF levels of PKE are a result of the cell wall content of the unprocessed materials (Moss & Givens, 1994). Moss & Givens (1994) reported that all the feedstuffs from the oil industry had a low starch content.

Most of the common minerals are within acceptable ranges (Alimon, 2004). However, the copper (Cu) content (21 - 28 ppm) exceeds the requirements of ruminants (Alimon, 2004). Previous studies where sheep were fed inclusions of 50% PKE showed that they may suffer of high Cu accumulations in the liver and develop Cu toxicity symptoms if fed for an extended period (Alimon, 2004). Calcium (Ca) supplementation is needed for diets based on PKE to meet the requirement of the animal, because the Ca to phosphorus ratio of PKE is low (<2:1) (Alimon, 2004).

Palm kernel expeller is a useful source of protein to ruminants (Alimon, 2004). The protein of PKE is high in methionine (Met) and low in lysine (Lys) and threonine (Thr) (Van Straalen *et al.*, 1997). Alimon (2004) added that the first limiting amino acid (AA) in PKE seems to be Lys followed by Met, cysteine (Cys) and tryptophan (Trp) and the average availability of the AA's are 85%.

Hutagalung & Mahyuddin (1985) reported that both PKE and SEPKC have high digestibility values (70 - 80%) of DM, organic matter and CP. Jalaludin *et al.* (1991) reported similar DM digestibility values and Moss & Givens (1994) additionally reported that the EE of PKM was very digestible. The DE of PKE is similar to many cereal feedstuff sources (Alimon, 2004). Wong & Zahari (1997) and O`Mara *et al.* (1999) reported similar DE for PKE, 13.37 and 13.4 MJ/kg respectively, whereas Chin (2001) reported a slightly higher DE of 14.89 MJ/kg for PKE. The disparity in measurement of the digestibility of nutrient fractions in PKE and ME content are due to the unusual composition of the cell wall of PKM, which is high in galactomannans (Everington, 1989). The ME content of PKM reported by labs not using gamanase enzymes during the digestibility analysis does not represent an accurate ME value but rather represents an underestimated ME value for PKM (Dowman, 1993; Moss & Givens, 1994). Therefore the results of ME analyses without the inclusion of gamanase enzymes, should be discarded.

2.4.3.3 Application

Palm kernel expeller is usually used for animal feeds rather than SEPKC (Carrión *et al.*, 2011), especially for ruminant diets because of its fibrous nature (Moss & Givens, 1994; Abdullah *et al.*, 1995). According to Zahari & Alimon (2003) PKE is used as a source of energy and fibre for dairy cattle at inclusion levels of 30 to 50%, however Carvalho *et al.* (2006) stated that PKM is generally included in small amounts (< 10%) in dairy concentrates due to its low palatability. Abdullah & Hutagalung (1988) reported complete defaunation of rumen liquor when cattle were fed a PKC-based diet *ad libitum*. Chanjula *et al.* (2010) reported that the digestibility of DM, protein and fibrous fractions as well as protozoal populations decreased in response to increased PKE inclusion levels (> 35% PKE). High level inclusions of PKE might lead to a higher passage rate of feed and reduced digestibility and feed efficiency due to increased fibre content (Carrión *et al.*, 2011). Most of the energy of PKE comes from oil and NDF, as PKE is very low in starch and sugars. This results in a very low risk of developing acidosis and other rumen health disturbances (Varga *et al.*, 1998). To establish sufficient rumination PKE should be fed with a long effective fibre source, because the NDF in PKE is low in effective fibre and has a small particle size (Varga *et al.*, 1998). Palm kernel expeller can also be fed raw at pasture to act as a pasture extender as used in Australia and New Zealand when pasture growth rate is low (P. Brönn; Personal communication, Intelact (Pty) Ltd, Eastern Cape, 2011, pbronn@farmvision.co.za).

Only one study investigating the effect of PKM on performance of dairy cows could be found. In this study, Carvalho *et al.* (2006) reported no significant treatment effects on DMI, milk yield, or milk composition when PKM was included in a total mix ration (TMR) at different inclusion levels (5, 10 and 15% inclusion), however the milk lactose tended to increase as PKM inclusion increased ($P < 0.10$). Carvalho *et al.* (2006) also reported that feed costs decreased without negative effects on productive responses when PKM was included up to 15% in a TMR. Unfortunately the PKM tested in the latter study was SEPKC and not PKE. The majority of studies regarding PKM on animal production were targeted on goats and beef cattle. Therefore, further research on the use of PKE in grazing dairy cows is urgently needed.

Table 2.4 Comparative nutrient composition of palm kernel expeller

Nutrient[1] (g/kg DM, or as stated)	Author						
	Yeong *et al.* (1983)	MAFF (1992)	Moss & Givens (1994)	O'Mara *et al.* (1999)	Chin (2001)	Alimon (2004)	Chanjula *et al.* (2010)
DM	-	-	922	883	916	880 - 945	959
Ash	-	44	45	49.5	42.0	30.0 - 120	39
CP	-	170	172	164	151	145 - 196	142
CF	-	-	211	238	149	130 - 200	-
NDF	-	693	685	801	664	668 - 789	689
ADF	-	470	441	543	418	-	527
ADL	-	68	-	181	-	-	147
EE	-	83	108	78.3	98.3	50 - 80	94
Starch	-	-	13	-	-	-	-
ME[2]	-	11.6	13.1	-	12.1	10.5 - 11.5	-
GE[2]	-	-	20.9	20.6	-	-	19.9
Ca	2.9	-	2.6	-	2.0 - 2.1	2.1 - 3.4	-
P	7.9	-	6.5	-	3.2 - 5.2	4.8 - 7.1	-
Ca:P ratio	0.4	-	0.4	-	0.4 - 0.6	0.4 - 0.5	-
Mg	2.7	-	3.2	-	-	1.6 - 3.3	-
K	-	-	7.4	-	-	7.6 - 9.3	-
S	-	-	-	-	-	1.9 - 2.3	-
Na	-	-	0.2	-	-	-	-
Cu (ppm)	28.5	-	-	-	18	20.5 - 28.9	-
Zn (ppm)	77	-	-	-	-	40.5 - 50.0	-
Fe (ppm)	405	-	-	-	-	835 - 6130	-
Mn (ppm)	225	-	-	-	-	132 - 340	-
Mb (ppm)	-	-	-	-	-	0.70 - 0.79	-
Se (ppm)	-	-	-	-	-	0.23 - 0.30	-

[1]DM – dry matter; CP – crude protein; CF – crude fibre; NDF – neutral detergent fibre; ADF – acid detergent fibre; EE – ether extract; ME – metabolisable energy; GE – gross energy; Ca – calcium; P – phosphorus; Ca:P – calcium to phosphorus ratio; Mg – magnesium; K – potassium; S – sulphur; Na – Sodium; Cu – copper; Zn – zinc; Fe – iron; Mn – manganese; Mb – molybdenum, Se - selenium
[2]MJ/kg DM

CHAPTER 3

Kikuyu/ryegrass pasture management and quality

3.1 Introduction

This chapter describes the establishment, yield measurement, grazing management and nutritive quality of the kikuyu/ryegrass pasture grazed by the experimental group cows in both the rumen (chapter 4) and production study (chapter 5). In this chapter the word 'pasture' will refer to the kikuyu/ryegrass pasture. The experimental cows in both studies grazed the pasture as one group at all times.

3.2 Materials and methods

3.2.1 Location, climate, and soil

The study was conducted at the Outeniqua Research Farm situated near George in the Western Cape Province of the Republic of South Africa (RSA). The altitude, latitude, and longitude are 204 metre (m) above sea-level, 33°58´38´´S and 22°25´16´´E, respectively. The George area has a temperate climate. The long term mean rainfall in this area over a period of 45 years, since 1967, is 731.45 mm per annum (ARC, 2011). The mean monthly minimum, maximum, and daily temperatures and total monthly rainfall during the duration of the study were recorded (ARC, 2011). The paddock where the study was conducted consists of two distinct soil forms namely an Estcourt form in the northern part of the paddock and a Witfontein form in the slightly downward sloping southern part (Soil Classification Working Group, 1991).

3.2.2 Camp design

Approximately 8.55 ha of permanent irrigated kikuyu/Italian ryegrass pasture were divided into 39 strips using electrical charged poly wire. The pasture consisted predominantly of ryegrass since kikuyu is dormant during August and September in the Southern Cape (Botha, 2003). Each strip had a length of 150 m and a width of 15 m except strip numbers 35 to 39, as shown in Figure 3.1. Nine irrigation heads were

spaced evenly over each dividing border between the strips, resulting in ten 15 m spaces within each strip, except strip number 35 to 39. Due to the latter, a standard was set so that each strip can be subdivided into known area sizes. The area size between two corresponding irrigation heads in a strip was 225 m^2 (15 m x 15 m) and was referred to as one irrigation head space. This standardisation was done to simplify the allocation of the specific pasture allocated to fulfil the needs of the experimental group Jersey cows. Cows grazing each strip had access to fresh unlimited water.

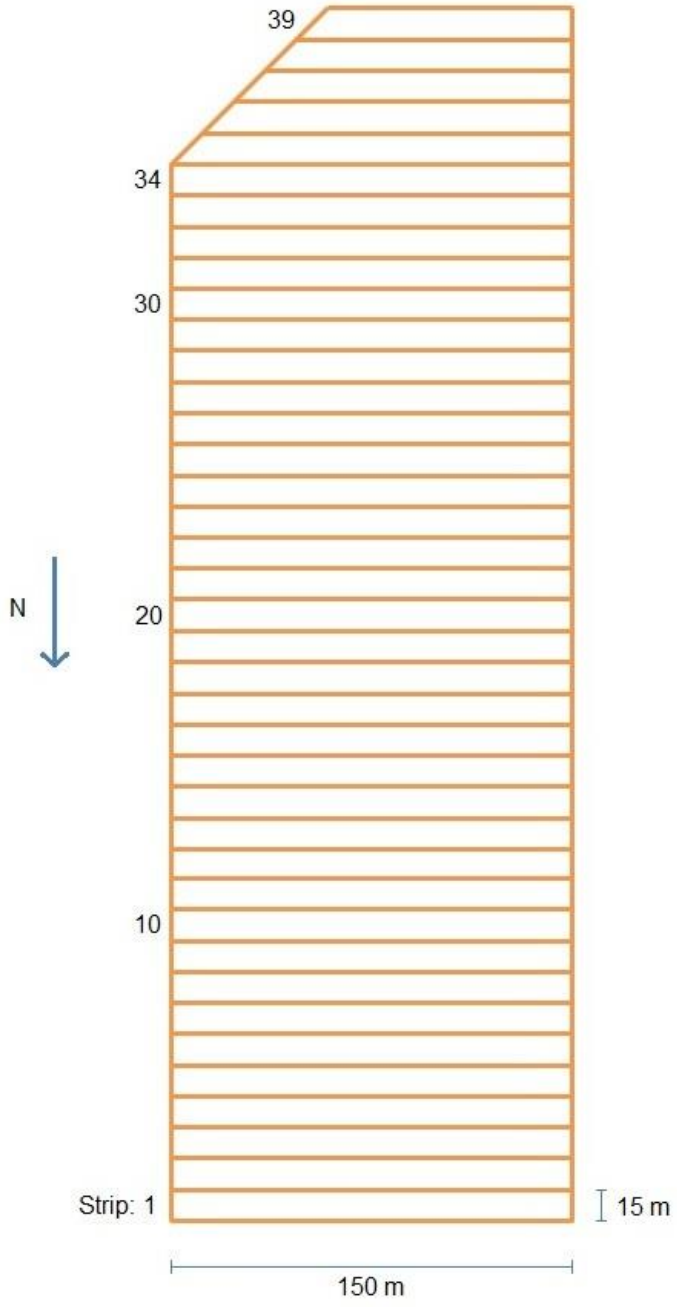

Figure 3.1 Camp design of the 8.55 ha kikuyu/Italian ryegrass pasture grazed by the Jersey cows in the study

3.2.3 Pasture establishment

Italian ryegrass (*Lolium multiflorum Lam*. var. *italicum*), an annual ryegrass, was over-sown into an 8.55 ha paddock of established kikuyu (*Pennisetum clandestinum*) pasture. Before the over-sowing method commenced, the kikuyu pasture was firstly grazed to a stubble height of 50 mm (rising plate meter (RPM) reading of 10), after which the pasture was mulched (Figure 3.2) to ground level (1.6 m Nobili with 24 blades) (Botha, 2003). The Italian ryegrass was established at a seeding density of 25 kg/ha into the mulched kikuyu pasture during March 2011 using a direct drill with no-till planter (2.4 m Aitchison 3116C seedmatic with 16 rows) as shown in Figure 3.3 after which the pasture was rolled with a 2.33 m Cambridge type light land roller (Figure 3.4) (Botha, 2003).

3.2.4 Animal welfare

Ethical clearance was obtained through the Western Cape Department of Agriculture and a DECRA approval number was issued: R11/34.

3.2.5 Pasture grazing, fertilisation and irrigation management

Jersey cows strip grazed the paddock from West to East as a group at a stubble height of 50 mm (RPM reading of 10) with one rotation after each milking, resulting in a 28 d grazing cycle. The allocated strip would facilitate specific pasture allocation. Each strip was top-dressed with 42 kg N/ha after grazing. The fertiliser used was limestone ammonium nitrate (LAN, 28% N). The related strip was irrigated if needed for 5 min directly after applying the fertiliser to ensure minimum N loss. Manual tensiometers were used to schedule the irrigation of the paddock. Irrigation was initiated at a tensiometer reading of -25 kPa and was ended at a reading of -10 kPa (Botha, 2002).

3.2.6 Pasture sampling and analyses

A total of six representative pasture samples (of 0.098 m^2 each) were cut at a stubble height of 30 mm (RPM reading of 6) on a weekly basis on the particular strip the day before grazing. The samples were dried at 60° C for 72 h (Botha, 2003) and weighed (Sartorius BP8100, weighing accurately to 0.1 g) to determine the DM content. The six pasture samples cut per week were pooled, and milled (SMC Hammer mill, 1 mm screen), resulting in a total of eight pooled pasture samples at the end of the study (after eight weeks). The samples were preserved in a freezer at

-20° C pending analyses at UP Nutrilab (Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria).

The pasture samples were analysed for DM (AOAC, 2000: procedure 934.01), ash (AOAC, 2000: procedure 942.05), CP (N determined using LECO Trumac^{TM} N Determinator, LECO Corporation, Saint Joseph, MI, USA, and CP = N x 6.25 (AOAC, 2000: procedure 968.06)). The fibre fractions analysed for were NDF (ANKOM technology method 9: Filter bag technique, ANKOM^{2000} fibre analyser; Robertson & Van Soest, 1981), acid detergent fibre (ADF) (ANKOM technology method 8: Filter bag technique, ANKOM^{2000} fibre analyser; Goering & Van Soest, 1970), acid detergent lignin (ADL) (Goering & Van Soest, 1970), acid detergent insoluble nitrogen (ADIN) (determined from having done both the ADF followed by the N analyses). Samples were also analysed for *in vitro* organic matter digestibility (IVOMD) (Tilley & Terry, 1963; using rumen fluid from a rumen-fistulated Dohne Merino ram, which was fed good quality Lucerne hay), starch (AOAC, 1984), EE (AOAC, 2000: procedure 920.39), GE (MC – 1000 Modular Calorimeter, Operators Manual), Ca (sample preparation: AOAC, 2000: procedure 935.13; sample analyses: Giron, 1973), and phosphorous (P) (AOAC, 2000: procedure 965.17). Metabolisable energy (MJ/kg DM) was calculated from IVOMD as follows: ME = 0.81 x GE x OMD for forages (ARC, 1984; MAFF, 1984). The following formula was used to calculate non fibre carbohydrate (NFC): NFC = [100 – (NDF + Ash + CP + EE)] (NRC, 2001).

Figure 3.2 The 1.6 m Nobili mulcher with 24 blades

Figure 3.3 The 2.4 m Aitchison 3116C seedmatic direct drill no-till planter with 16 rows

Figure 3.4 The 2.33 m Cambridge type light land roller

3.2.7 Pasture dry matter yield measurement

Pasture DM yield per area was estimated by using the RPM with a disk area of 0.098 m^2 (Figure 3.5), by taking the mean of 100 RPM readings in a zigzag pattern on each pasture strip the day before and after grazing. A seasonal regression was determined by weekly cutting nine circles (three of each low, medium, and high sward heights being representative of the rest of the pasture in that strip) at a stubble height of 30 mm (a RPM reading of 6) after measuring the height of the pasture with the RPM. A metal ring that was the exact size as the RPM disk was used to obtain the circles. The cut samples were dried at 60° C for 72 h (Botha, 2003) to determine the DM content and hence DM yield. The seasonal regression is a linear model

correlating RPM reading with pasture DM yield (Earle and McGowan, 1979) as shown in the following equation: Y = (a x H) + b, where 'Y' = dry matter yield (kg DM/ha), 'a' = gradient, 'H' = recorded height of RPM, an 'b' = intercept value.

Figure 3.5 Rising plate meter used to measure pre- and post-grazing, and to determine the seasonal regression

3.2.8 Pasture allocation

Pasture was offered at *ca.* 10 kg DM/cow/day above 30 mm (RPM reading of 6) to ensure that pasture intake was not limiting. Based on previous experience, strip length prior to grazing was determined by the available DM herbage present on the strip above 30 mm, which was calculated using the generalised seasonal regression: Y = (H x 70) – 420, where 'Y' = herbage DM yield (kg DM/ha) and 'H' = recorded height of RPM, which was cumulated from regression equations determined by Van der Colf (2011). This regression equation was specifically developed for kikuyu over-sown with Italian ryegrass during spring and was used for pre- and post-grazing estimations. An after-grazing height of 50 mm (RPM reading of 10) was maintained by adjusting the allocated kilogram DM pasture per cow given the DM yield per hectare calculated by the generalised regression.

3.3 Results and discussion

3.3.1 Climate

The total monthly rainfall and mean monthly maximum and minimum temperatures of the duration of the study (August 2011 to November 2011) are shown in Figure 3.6 compared to long term data for the Outeniqua Research Farm compiled from 1967 to 2011 by the ARC (2011). As can be seen from the graph, the region had rain throughout the study period. According to ARC (2011), the long term annual rainfall for this region over a period of 45 years is 731.45 mm per annum. A total of 918.72 mm rain fell in the year of the study. August and November showed above average rainfall, whereas September and October showed below average rainfall during the period of the study. The latter did not affect the study negatively, as reserved water was available for irrigation. The total rainfall during the duration of the study from August to November was 11 mm above the long term average over that period.

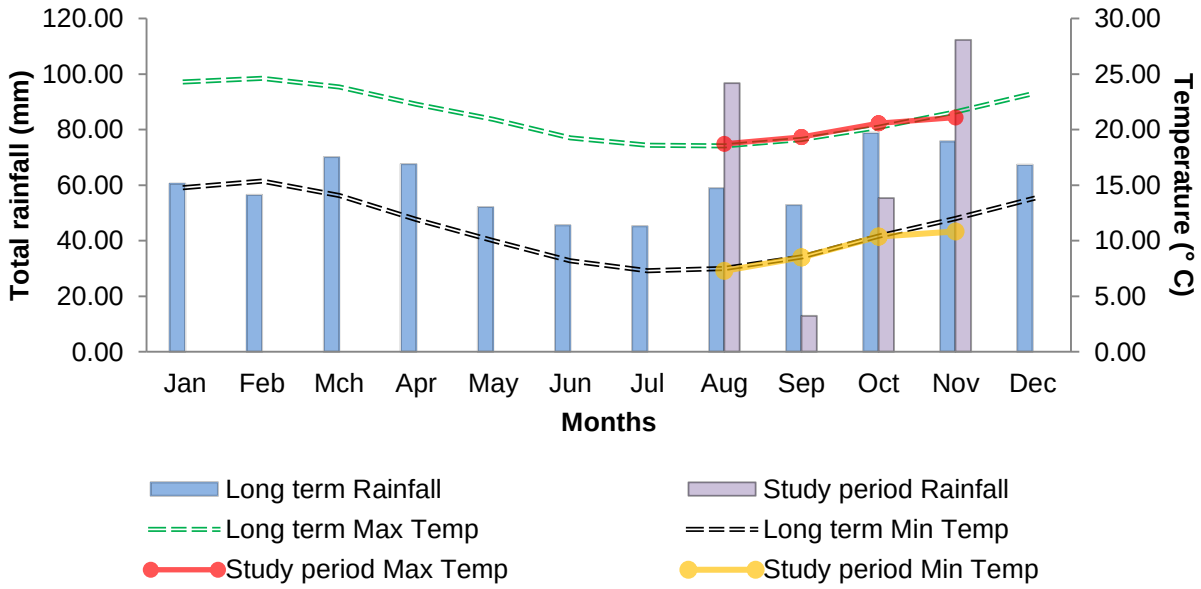

Figure 3.6 The total monthly rainfall and mean monthly maximum and minimum temperatures for the duration of the study (August 2011 to November 2011) compared to long term data (from 1967 to 2011) for the Outeniqua Research Farm

The mean monthly maximum and minimum temperatures for the duration of the study were in close comparison to that of the long term averages. The George area has a temperate climate, therefore the temperatures experienced during the study period was as expected.

3.3.2 Pasture management

The calculated seasonal regression for which kikuyu/ryegrass was cut throughout the extent of the study generated the following equation: Y = 119.94*H – 897.71, where 'Y' = available DM herbage and 'H' = RPM reading, Figure 3.7. This calculated seasonal regression was only implemented after the conclusion of the study and was used as a single regression for pre- and post-grazing estimations.

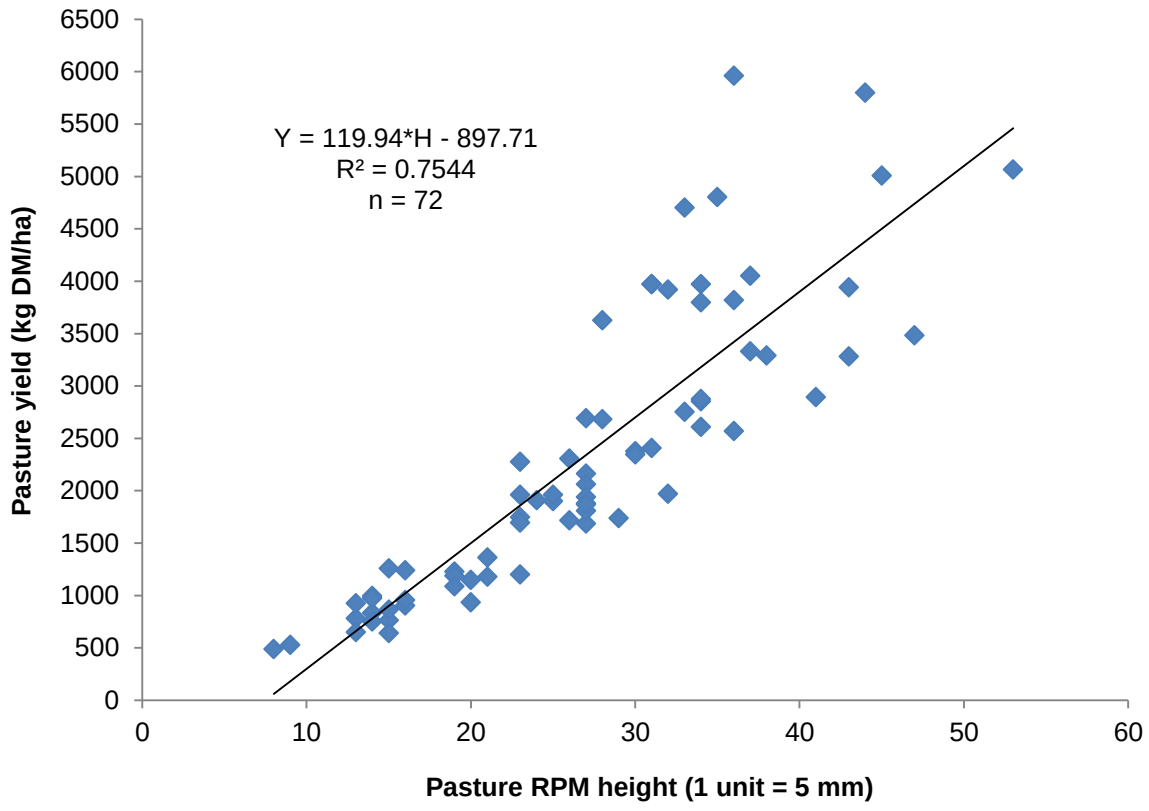

Figure 3.7 The seasonal regression correlating rising plate meter (RPM) reading with kikuyu/ryegrass pasture yield (kg DM/ha) used throughout the study

The RPM is inaccurate in determining individual pasture DMI (Reeves *et al.*, 1996b); however this was not the purpose for the use of the RPM in this study. The RPM was used as a management tool for correct pasture allocation to ensure adequate pasture availability and to monitor post-grazing heights. Correct pasture management involves accurate pre- and post-grazing measurements of pasture height to ensure correct pasture allocation for the grazing cow.

Cows were allocated a new strip after each milking period, resulting in short grazing periods that increases the reliability of the RPM (Smith *et al.*, 2005a). The paddock (Section 3.2.2) utilised in the study period was grazed three times at the end of the study. The pasture parameters collected over the period of the study are depicted in Table 3.1. The post-grazing RPM reading (Table 3.1) was kept in the range of 10 – 12 RPM reading as specified by Stockdale (2000) that indicates a well utilised pasture and ensures optimal pasture regrowth and quality. The pasture allowance presented in Table 3.1 exceeds that stated in Section 3.2.8 (*ca.* 10 kg DM/cow/day). The reason for the over-estimation is due to the use of a generalised seasonal regression (Van der Colf, 2011) to determine pasture yield, hence pasture allocation, during the study period. This highlights the importance to use a calculated regression that refers directly to the specific area, specific pasture and specific season that were used and occurred during the study period (Sanderson *et al.*, 2001). Ultimately pasture intake was met and the pasture was not over-utilised.

The difference observed in pasture allowance and pasture intake (Table 3.1) accumulates to over-estimated pasture availability. The reason for this is that the regression is cut at 30 mm (RPM reading of 6) above the ground, whereas cows are allowed to graze pasture up to 50 mm (RPM reading of 10) above the ground. This is done to apply a safety margin if cows do graze below 50 mm. Trampled and contaminated (with faeces and urine) pasture contributes furthermore to the difference in pasture allowance and pasture intake, decreasing the potential pasture intake.

Table 3.1 Mean and standard deviation of the pre- and post-grazing rising plate meter readings (n = 109), pasture yield, pasture allowance and pasture intake determined using the single calculated regression (Y = 119.94*H – 897.71)

Parameter[1]	Pasture Values
Pre-grazing	
RPM reading	24.7 ± 3.2
Pasture yield (kg DM/ha)	2061 ± 378
Pasture allowance (kg DM/cow/day)	11.1 ± 1.5
Post-grazing	
RPM reading	10.7 ± 0.9
Pasture yield (kg DM/ha)	388 ± 109
Pasture removed (kg DM/ha)	1674 ± 368
Pasture intake (kg DM/cow/day)	9.0 ± 1.4

[1]RPM – rising plate meter; DM – dry matter
± - Mean and standard deviation

3.3.3 Pasture quality

Pasture quality parameters affected by the progression from early to late spring of kikuyu/ryegrass pasture samples collected over an eight week period during the study are depicted in Figure 3.8. A trend in the nutritive composition of the pasture is visible as spring progressed. The DM, NDF, ADF and ADL of the pasture increased, accordingly the ME and IVOMD of the pasture decreased. These results are in agreement with the findings of several authors (Bargo *et al.* 2003; Meeske *et al.*, 2006; Fulkerson *et al.*, 2007; Van der Colf, 2011; Steyn, 2012) stating that pasture (predominated by ryegrass) quality decreases as the season progresses. The CP value of the pasture increased variably during the progression of spring, albeit a decrease was expected (Van Vuuren *et al.*, 1991). Several climatic factors, such as rainfall and temperature, could influence the N volatility and leaching at the time of fertilisation, and therefore, the CP content of the pasture (Carruthers & Neil, 1997). The marginal variability in CP could also be due to excessive N fertilization, albeit N fertilisation was set at 42 kg N/ha for this study, which is considered as a low N fertilisation level. The ADF levels are well above the recommended 19 to 21% ascribed by the NRC (1989) to prevent milk fat depression.

The mean nutrient composition of the kikuyu/ryegrass pasture utilised during the study period in spring, as shown in Table 3.2, are in close comparison with values reported by several authors in the literature review (Table 2.1). The CP value (21.5%) of the pasture in the current study is well in the range of 15.6 to 29.8% (average of 24.3%) for ryegrass, as specified by Van Vuuren *et al.* (1991). The NDF value (49.4%) of the pasture in the current study fell within the range of 40.0 to 52.7%, as reported by Muller & Fales (1998) for cool-season grass pasture. The lower CP value for the pasture obtained from this study, compared to CP values in the literature review (Table 2.1), is due to applying only 42 kg N/ha on the pasture in this study, whereas higher CP values in the literature review are correlated with higher pasture N applications per hectare. However the pasture utilised during this study can be categorised as a high quality pasture according to the requirements set by Clark and Kanneganti (1998): 40 – 50% NDF and >18% CP.

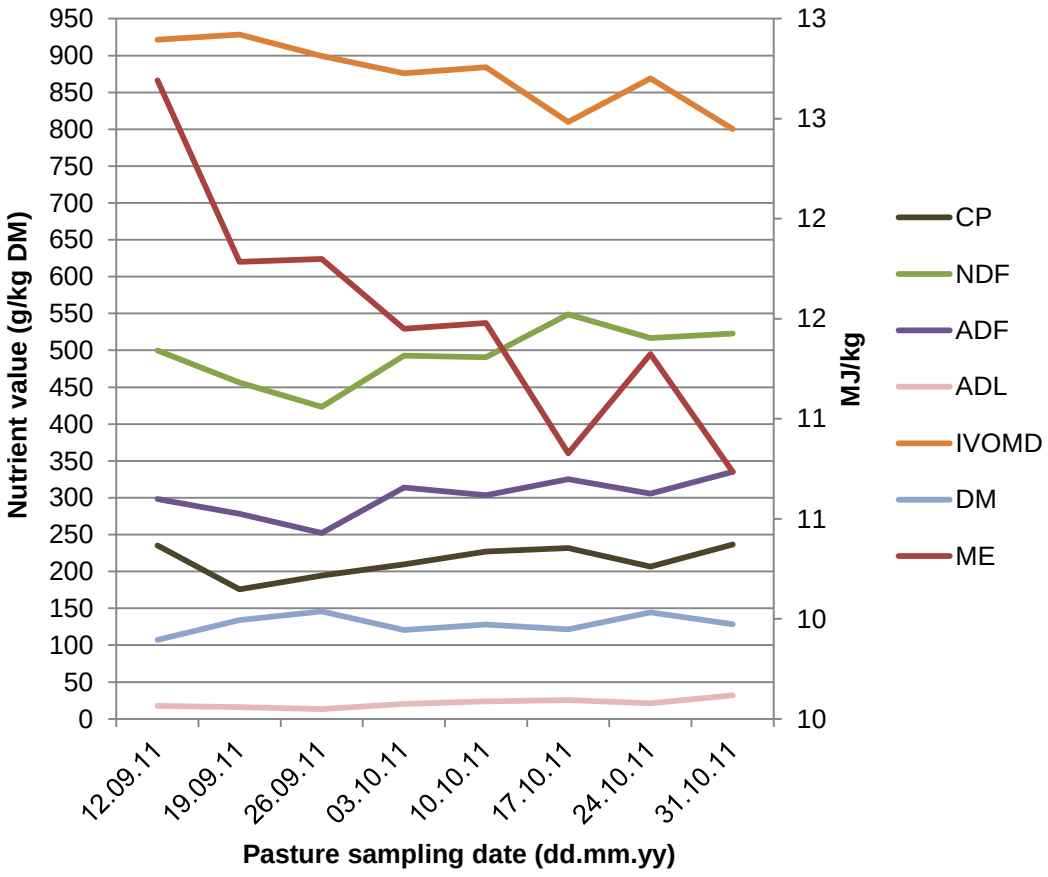

Figure 3.8 Pasture quality parameters affected by the progression from early to late spring of kikuyu/ryegrass pasture samples collected over an eight week period during the study

Table 3.2 Mean and standard deviation of the nutrient composition of the kikuyu/ryegrass pasture (n = 8) utilised by Jersey cows during spring (study period)

Nutrient[1] (g/kg DM, or as stated)	**Kikuyu/ryegrass pasture**
DM	128.7 ± 12.8
OM	893.6 ± 9.2
IVOMD (%)	80.22 ± 2.49
ME (MJ/kg)	11.51 ± 0.62
NFC	153.8 ± 64.9
CP	214.7 ± 21.9
CP:ME ratio	1.87 ± 0.24
NDF	493.9 ± 39.4
ADF	301.5 ± 26.3
ADL	21.2 ± 5.8
Starch	13.2 ± 3.7
ADICP (% of CP)	124.6 ± 17.4
EE	39.6 ± 3.8
Ca	3.8 ± 0.4
P	3.4 ± 0.5
Ca:P ratio	1.12 ± 0.17

[1]DM – dry matter; OM – organic matter; IVOMD – in vitro organic matter digestibility; ME – metabolisable energy (calculated); NFC – non fibre carbohydrate (calculated); CP – crude protein; CP:ME ratio – crude protein to metabolisable energy ratio; NDF – neutral detergent fibre; ADF – acid detergent fibre; ADL – acid detergent lignin; ADICP – acid detergent insoluble crude protein (ADIN x 6.25); EE – ether extract; Ca – calcium; P – phosphorous; Ca:P – ratio between calcium and phosphorous
± - Mean and standard deviation

CHAPTER 4

Effect of palm kernel expeller supplementation on performance of Jersey cows grazing kikuyu/ryegrass pasture

4.1 Introduction

The research study consisted of two distinct studies, namely a lactation production study and a fundamental rumen study using rumen-fistulated cows. The two studies were conducted in tandem. The lactation production study will be described in this Chapter and the rumen study will be described in Chapter 5. The lactation production study was conducted at the Outeniqua Research Farm situated near George in the Western Cape to determine the effect of different PKE inclusion levels in dairy concentrates for Jersey cows on milk production, milk composition, BW and BCS. The cows used in the production study grazed with the lactating rumen-fistulated cows as one group utilising the same pasture. The cows from the two studies were milked together according to their allocated treatment groups. The rumen study was not provoked by any means during the duration of the lactation production study.

4.2 Materials and methods

4.2.1 Location, climate and soil

See Section 3.2.1 of Chapter 3 for details regarding the location, climate and soil of this study.

4.2.2 Animal welfare

See Section 3.2.4 of Chapter 3 for details regarding animal welfare.

4.2.3 Duration of the study

The experimental study started the 12th of August 2011 and was completed the 1st of November 2011. A period of 21 d was allowed for adaptation (7 d on the pasture with *ad libitum* access to PKE only followed by 14 d of feeding the allocated treatment concentrates in the milking parlour). Palm kernel expeller only was fed in feeding troughs on pasture during the first 7 d adaptation period. Due to practical

constraints all treatment cows had access to PKE only during this period. This was done to allow cows to become accustomed to the low palatable PKE. The lactation production study commenced after the adaptation period where data was collected over a period of 60 d.

4.2.4 Grouping of cows

Forty-eight multiparous high producing Jersey cows from the Outeniqua Research Farm herd were used. First lactation cows as well as cows not in the lactation stage of 20 to 164 DIM were excluded from the study due to the variability often experienced in the milk production of such animals. The cows were blocked according to 4% FCM production which was calculated using the previous milk production average from 25 July to 15 August 2011 and the milk fat percentage of the previous lactation, DIM as from the 17th of August 2011 and lactation number (Table 4.1). See Table A1 in Appendix A for more detail. The Gaines formula was used to calculate 4% FCM, where 4% FCM = [0.4 x kg milk] + [15 x kg milk fat] (Gaines, 1928), therefore correcting for variation in milk composition. Cows within blocks were randomly (random function in Microsoft Excel, 2010) allocated to one of three treatment groups (control, low PKE, and high PKE) resulting in sixteen cows per treatment. Additionally, four lactating rumen-fistulated cows were randomly assigned merely to the control and high PKE treatment (rumen study, Chapter 5). In addition, four non-participant lactating cows were assigned to the low PKE treatment resulting in twenty cows per group. This was done to have all the spaces filled in the dairy parlour as cows are fed and milked in groups of twenty in the milking parlour. This is a practical constraint of the milking system.

The cows grazed kikuyu/Italian ryegrass pasture as one group for 24 h per day except during milking times when they received their concentrate supplementation in the milking parlour. The cows were collected from pasture as deferred as possible and returned after milking as swiftly as possible in a calm and collected approach. Before each milking session cows of the different treatment groups were separated. To simplify the process, each cow was labeled with a coloured tag attached to a light metal chain that was tightened around the neck using a cable tie (Figure 4.1). Pink tags represented the cows allocated to the control treatment, green for cows allocated to the low PKE treatment, and yellow for the cows allocated to the high

PKE treatment. Cows had *ad libitum* access to clean water before and after milking, and during grazing.

Table 4.1 The mean and standard deviation of milk yield and 4% fat corrected milk production (FCM; as from 25 Julie to 15 August 2011), and milk fat content of the previous lactation, days in milk (DIM; as of the 17th of August 2011), lactation number, body weight (BW), and body condition score (BCS) of each treatment after blocking (n = 16)

Parameters[1]	**Treatment concentrate**[2]		
	Control	**Low PKE**	**High PKE**
Milk Yield (kg/cow/d)	23.5 ± 3.6	23.8 ± 4.0	23.9 ± 3.5
Milk fat (g/kg)	50.5 ± 1.9	49.6 ± 2.4	49.9 ± 2.1
FCM (kg/cow/d)	27.2 ± 3.9	27.2 ± 4.4	27.4 ± 3.9
DIM (d)	82.3 ± 42.6	88.6 ± 35.5	79.8 ± 43.6
Lactation nr	3.5 ± 1.7	4.2 ± 1.9	4.1 ± 1.8
BW (kg)	375 ± 34	363 ± 39	373 ± 39
BCS (scale 1 to 5)	2.4 ± 0.3	2.3 ± 0.4	2.3 ± 0.4

[1]FCM – 4% fat corrected milk (calculated); DIM – days in milk; BW – body weight; BCS – body condition score
[2]Control – concentrate containing 0% PKE; Low PKE – concentrate containing 20% PKE; High PKE – concentrate containing 40% PKE; PKE – palm kernel expeller
± - Mean and standard deviation

Figure 4.1 Jersey cow with a coloured tag attached to a light metal chain tightened around her neck to facilitate in the sorting into their respective groups prior to milking

4.2.5 Pasture and feed allocation

See Section 3.2.8 of Chapter 3 for details regarding the pasture allocation. Concentrates of the different treatments were fed individually to cows at a rate of 3 kg/cow/milking (as is) in the milking parlour resulting in 6 kg concentrate/cow/d. Cows were milked twice daily, 05:30 AM and 15:30 PM, respectively. The nutrient composition of PKE (imported from Indonesia by Pieter Brönn, Intelact (Pty) Ltd, Eastern Cape, 2011, pbronn@farmvision.co.za) was determined before treatment concentrates were mixed (Animal Production Laboratory, University of Stellenbosch, 2011) as shown in Table 4.2. The PKE inclusion content of the control, low PKE, and high PKE treatments were 0, 20, and 40% respectively as shown in Table 4.3 (Nova feeds George, Industrial Area, George Western Cape, South Africa). Concentrates were balanced to be *iso*-nitrogenous. Molasweet (Nutec Explicit Nutrition, Block G, Hilton Quarry Office Park, 400 Old Howick Road, Hilton, KZN), a powdered palatant was added at 160 g/t to each of the three treatment concentrates to enhance palatability.

NOVA feeds (Nova feeds George, Industrial Area, George, Western Cape, South Africa) formulated, mixed, and bagged (50 kg) ten tons of each of the three treatment concentrates. The concentrates could not be pelleted, because the PKE inclusion levels exceeded that of NOVA feeds' recommendations. A maximum of 4% PKE can be included in the feed for it to be pelleted due to the detrimental action of small stones in PKE on the pellet machine. Treatments were bagged in different colours namely white (control), green (low PKE treatment), and yellow (high PKE treatment). Three kilograms of each of the treatment concentrates were manually weighed (Bizerba FC.15 scale with 0.1 g accuracy) into plastic bags.

Table 4.2 The nutrient composition of PKE that was included at different levels in each of the three treatment concentrates

Nutrient[1] (g/kg, DM basis or as stated)	**PKE supplement[2]**
DM	898
Ash	46.6
CP	190
ME (MJ/kg)	8.40
IVOMD (%)	50.5
NDF	778
ADF	552
EE	102
Mg	3.3
K	8.4
Ca	5.6
P	7.4
Ca:P ratio	0.76

[1]DM – dry matter; CP – crude protein; ME – metabolisable energy; IVOMD – in vitro organic matter digestibility; NDF – neutral detergent fibre; ADF – acid detergent fibre; EE – ether extract; Mg – magnesium; K – potassium; Ca – calcium; P – phosphorous; Ca:P – ratio between calcium and phosphorous
[2]PKE – palm kernel expeller

Table 4.3 The formulated ingredient and nutrient composition of each of the three treatment concentrates fed to Jersey cows grazing kikuyu/ryegrass pastures[1]

Ingredient[2] (g/kg)	**Treatment concentrate[4]**		
	Control	**Low PKE**	**High PKE**
Ground maize	816	657	499
PKE	0	200	400
Soybean oilcake	105	66	25
Molasses	50	50	50
Feedlime	15	14	13
Salt	6.0	6.0	6.0
MgO	3.0	2.5	2.0
Vitamin and Mineral Premix[5]	5.0	5.0	5.0
Nutrient[3] (g/kg, DM basis or as stated)			
DM	862	869	877
Ash	52.2	59.8	66.1
CP	126	126	125
RUP (% of CP)	48.1	47.8	47.3
ME (MJ/kg)	12.9	12.4	11.8
NFC	705	561	422
NDF	83.5	212	339
ADF	26.7	139	251
EE	33.6	41.4	47.9
Mg	3.8	3.6	3.3
Ca	7.4	7.3	7.1
P	2.8	3.3	3.8
Ca:P ratio	2.7	2.2	1.9

[1]NOVA feeds formulation data base (NOVA feeds George, George, Western Cape, SA)
[2]PKE – palm kernel expeller; MgO – magnesium oxide
[3]DM – dry matter; CP – crude protein; RUP – rumen undegradable protein; ME – metabolisable energy; NFC – non fibre carbohydrate; NDF – neutral detergent fibre; ADF – acid detergent fibre; EE – ether extract; Mg – magnesium; Ca – calcium; P – phosphorous; Ca:P – ratio between calcium and phosphorous
[4]Control – concentrate containing 0% PKE; Low PKE – concentrate containing 20% PKE; High PKE – concentrate containing 40% PKE
[5]Premix (Coprex Dairy Premix) – (per unit of premix) 6 million IU vitamin A; 1 million IU vitamin D3; 8000 IU vitamin E; 100 g Zn, 50 g Mn, 20 g Cu, 1.7 g I; 1 g Co; 300 mg Se
[*]Molasweet added at 160 g/t in each concentrate treatment

4.2.6 Concentrate sampling and analyses

Weekly grab samples of each concentrate treatment were taken and pooled every 14 days, resulting in twelve concentrate samples (four for each treatment) at the end of the study. The samples were dried at 60° C for 72 h (Botha, 2003) and weighed (Sartorius BP8100, weighing accurately to 0.1 g) to determine the DM content, and ground (Retch Ultra Centrifugal Mill ZM200, Rheinische Strobe 36, Germany) to pass a 1 mm screen and stored in sealed bottles. The samples were preserved in a freezer at -20° C pending analyses at UP Nutrilab (Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria).

The concentrate samples were analysed for the same nutrient fractions using the same analytical methods as for the pasture samples (Section 3.2.6, 2nd paragraph), whereas only ME was calculated differently by using the following equation: ME = 0.84 x GE x OMD (ARC, 1984; MAFF, 1984).

4.2.7 Milking procedure and milk yield

Cows covered an average distance of 800 m before and after each milking procedure as one group. Prior to each milking session, cows were sorted and divided into their corresponding treatment groups facilitated by the coloured tags. Cows were milked twice daily at 05:30 AM and 15:30 PM, respectively, using a twenty point Dairy Master swing over milking parlour with weigh-all electronic milk meters (Total Pipeline Industries, 33 Van Riebeeck Street, Heidelberg, 6665) (Figure 4.2). A refined milking procedure was followed ensuring sustainable udder health and wellbeing of cows during each milking session. Before cows entered the milking parlour, the corresponding concentrate of each cow was manually placed into the clean feeding troughs, spaced evenly in the milking parlour to ensure that each cow consumed the correct amount and type of feed.

Milk yield of individual cows were electronically measured and recorded during each milking procedure. Milk yield per day was determined on pooled morning and afternoon milking data, and the monthly average milk yield per cow per day and per treatment was calculated. The energy corrected milk production (ECM) was calculated from the latter milk data using the following equation: ECM = (0.3246 x kg Milk) + (12.86 x kg Milk fat) + (7.04 x kg Milk protein) (Gehman *et al.*, 2006).

Figure 4.2 Twenty-point Dairy Master swing over milking parlour with weigh-all electronic milk meters used during the study to obtain milk data

4.2.8 Milk sampling

Pooled morning and afternoon milk samples for each cow were taken every 14 days. To obtain a representative sample, 1 ml of milk sample was collected for every one hour between milking intervals. The milking interval between the afternoon and morning milking was 14 h, and 10 h between the morning and afternoon milking. This resulted in collecting 14 ml in the morning and 10 ml in the afternoon respectively, hence a representative 24 ml sample for each cow. Sampling was implemented according to a standardised procedure by gently tilting the sampling bottle three times to allow for even distribution of milk fat and milk contents before measuring into smaller samples. Milk samples were preserved in potassium dichromate ($K_2Cr_2O_3$). Five milk samples were collected for each cow during the experimental period.

Preserved samples were transported over-night to Lactolab (Irene, Pretoria, 0062) where milk components (milk fat, protein, and lactose), MUN, and SCC analyses were performed. Milk component analysis was done using the Fourier Transform Spectrometer technology by means of the Bentley FTS (Bentley Instruments Inc., Minnesota, USA, 55318), MUN analysis was done by means of a ChemSpec 150 (Bentley Instruments Inc., Minnesota, USA, 55318) that utilises a modified Berthelot reaction, and SCC analysis was performed using flow cytometry

by means of the Somacount FCM (Bentley Instruments Inc., Minnesota, USA, 55318).

4.2.9 Body weight and body condition scores

Cows were weighed on a Tru-Test EziWeigh version 1.0 scale (0.5 kg accuracy, Auckland, New Zealand) and body condition scored before the study commenced to obtain a starting BW and BCS for each cow. This was done after morning milking, to ensure empty udders, and pooled over two consecutive days to compensate for variation between days for each cows' pasture and water intake, urination, and defecation. The scoring system with a one to five scale was used to determine the body condition of the cows (Wildman *et al.*, 1982). Scoring was focused only on appearance and palpation of back and hind quarters and was performed subjectively by Gerrit van der Merwe (Jersey herd manager at the Outeniqua Research Farm). At the end of the study all of the cows were weighed and condition scored once more to obtain an end BW and BCS for each cow following the same procedure. The mean BW and BCS was calculated for each treatment group for the start and end period and was used to calculate the change in BW and BCS over the study period.

4.2.10 Concentrate refusals

Concentrate refusals of each cow were collected in separate plastic bags after each milking. These concentrate residues were manually weighed (as is) (Bizerba FC.15 scale with 0.001 g accuracy) and recorded per cow per treatment. Dry matter basis was not determined due to time and labour constrains, and was not essential as the concentrate refusals were not used for DMI calculations but rather for observational reasons, e.g. unhealthy cows.

4.2.11 Statistical analysis

The production study data were analysed statistically as a randomised block design with three treatments randomly (random function in Microsoft Excel, 2010) allocated to 16 blocks. The GLM model (Statistical Analysis Systems Institute, 2012) was used for the average effects over time. Repeated measures analysis of variance (ANOVA) with the GLM model was used for repeated period measures. Means and standard error were calculated and significance of difference ($P \leq 0.05$) between means was determined by Fischers test (Samuels, 1989). Tendencies were declared at $P < 0.10$. The linear model used is described by the following equation:

$$Y_{ij} = \mu + T_i + B_j + e_{ij}$$

Where Y_{ij} = variable studied during the period

μ = overall mean of the population

T_i = effect of the i^{th} treatment

B_j = effect of the j^{th} block

E_{ij} = random error associated with each Y

4.3 Results & discussion

4.3.1 Nutrient composition of the treatment concentrates

Table 4.4 represents the actual nutrient composition of the sampled feed of each treatment concentrate that was allocated to the cows during the study period, whereas Table 4.3 only represents the estimated nutrient composition as determined by NOVA feeds.

Table 4.4 Mean and standard deviation of the nutrient composition of each of the three treatment concentrates (n = 4) fed to the cows during the rumen study and production study

Nutrient[1] (g/kg, DM basis or as stated)	Treatment concentrate[2]		
	Control	Low PKE	High PKE
DM	886 ± 3.0	893 ± 1.3	901 ± 1.1
OM	946 ± 0.9	942 ± 2.4	941 ± 0.3
IVOMD (%)	92.0 ± 1.3	87.2 ± 0.8	81.6 ± 0.6
ME (MJ/kg)	13.2 ± 0.1	12.7 ± 0.1	12.2 ± 0.1
NFC	696 ± 16	596 ± 9	472 ± 13
CP	123 ± 3	121 ± 2	123 ± 0.3
CP:ME ratio	0.93 ± 0.03	0.95 ± 0.01	1.00 ± 0.01
NDF	103 ± 12	188 ± 6	295 ± 12
ADF	41.3 ± 8.8	105 ± 5	182 ± 14
ADL	11.5 ± 1.5	30.3 ± 1.8	58.2 ± 4.7
Starch	608 ± 25	510 ± 1	395 ± 8
EE	26.2 ± 1.3	39.2 ± 2.8	53.9 ± 1.6
Ca	6.7 ± 0.5	8.5 ± 0.3	8.4 ± 0.2
P	2.9 ± 0.1	3.4 ± 0.1	3.9 ± 0.1
Ca:P ratio	2.3 ± 0.3	2.5 ± 0.1	2.1 ± 0.1

[1]DM – dry matter; OM – organic matter; IVOMD – in vitro organic matter digestibility; ME – metabolisable energy (calculated); NFC – non fibre carbohydrate (calculated); CP – crude protein; CP:ME ratio – crude protein to metabolisable energy ratio; NDF – neutral detergent fibre; ADF – acid detergent fibre; ADL – acid detergent lignin; EE – ether extract; Ca – calcium; P – phosphorous; Ca:P – ratio between calcium and phosphorous
[2]Control – concentrate containing 0% PKE; Low PKE – concentrate containing 20% PKE; High PKE – concentrate containing 40% PKE; PKE – palm kernel expeller
± - Mean and standard deviation

The concentrates were formulated to be *iso*-nitrogenous and this can be confirmed by the homogeneous CP content of the concentrates observed in Table 4.4. The control concentrate can be described as a high starch/low fibre-based concentrate, the low PKE concentrate as a medium starch/medium fibre-based concentrate and the high PKE concentrate as a low starch/high fibre-based concentrate, respectively. This is due to the decrease in ME, starch, NFC and IVOMD, and the increase in NDF, ADF, ADL levels in the order of control<low PKE<high PKE concentrate.

The results obtained for the nutritional composition of the concentrates compares well with the estimated nutrient composition formulated by NOVA feeds, which confirms that the concentrates were correctly and thoroughly mixed.

4.3.2 Effect of palm kernel expeller supplementation on milk yield

The mean milk yield, 4% FCM and milk composition of cows on the different treatments are presented in Table 4.5. The milk yield, 4% FCM and ECM were similar between cows receiving the control, low PKE and high PKE treatments ($P > 0.05$). As PKE inclusion increased the maize inclusion decreased in the concentrate. This resulted in a lower ME content in the concentrate as the PKE inclusion increased (Table 4.4). Even at the lower energy content of the high PKE concentrate at a daily intake of 6 kg (12.2 MJ ME/kg DM) and an estimated pasture DMI of 9.0 kg with an energy content of 11.5 MJ ME/kg DM , the energy requirement of 162 MJ ME would have been satisfied (NRC, 2001). Feeding the higher energy control concentrate, therefore, exceeded the energy requirement for cows producing 22 kg milk/d (NRC, 2001). It could be speculated that cows receiving the lower energy content concentrates (low and high PKE treatments) had a higher pasture DMI compared to the cows receiving the control concentrate. This is due to compensate for the lower energy content in the low and high PKE concentrates compared to the control diet. Individual pasture intake measurement was, however, needed to confirm this statement.

Previous grazing studies reported similar milk yields comparing fibre-based to starch-based concentrates ($P > 0.05$; Delahoy *et al.*, 2003; Sayers *et al.*, 2003; Gehman *et al.*, 2006; Meeske *et al.*, 2009; Lingnau, 2011). Meijs (1986) and Khalili & Sairanen (2000), however, reported increased milk production ($P < 0.05$). Meijs (1986) replaced corn and cassava (starch-based) with soybean hulls and beet pulp

(fibre-based), and Khalili & Sairanen (2000) replaced rolled barley with oats, wheat bran and beet pulp, respectively. A review done by Bargo *et al.* (2003) stated that the overall milk production reduced slightly (-0.46 kg/d) when starch-based concentrates are replaced by fibre-based concentrates fed to grazing dairy cows, however the milk response ranged from -2.6 to 1.3 kg/d. The results of the current study are difficult to compare with previous published studies, because no studies could be found where the effect of PKE supplementation was tested on the milk production of dairy cows, even with PKE being a common raw material component in formulated dairy diets. One study was found where the effect of SEPKC supplementation was tested on dairy cows up to an inclusion level of 15% in a TMR (Carvalho *et al.*, 2006). The milk yield and 4% FCM of the current study are in agreement with the results obtained by Carvalho *et al.* (2006) who found no differences in milk yield and 4% FCM ($P > 0.05$).

The optimum starch concentration in TMR diets fed to high producing dairy cows is not well defined, but 24 – 26% starch has been suggested (Staples, 2007). In a survey amongst 27 high producing herds in the USA (> 13 000 kg/lactation), starch concentrations varied from 25 – 30% of dietary DM (Kaiser & Shaver, 2006). Recently, high maize prices have forced nutritionists to replace some maize with highly digestible non forage fibre sources such as citrus pulp, soyhulls, maize gluten and distillers' grains. It was concluded that maize can be replaced with by-product feeds resulting in low starch diets (16 – 21%) without adverse effects on ruminal fermentation and lactational performance (Shaver, 2008). Our results support this concept, although this was a pasture-based study. The starch content of the control concentrate was 60.8% compared to 39.5% starch in the high PKE concentrate. Assuming a pasture DMI of 9.0 kg and starch content of 1.3% this would result in a total dietary starch content of 23.6% and 15.8%, respectively for the control and high PKE treatment concentrates.

According to Gehman *et al.* (2006), increased DMI is one of the advantages that fibre-based concentrates have over starch-based concentrates. Meijs (1986) and Sayers *et al.* (2003) reported that total DMI were increased, 0.7 and 0.8 kg/d, respectively, when fibre-based concentrate replaced starch-based concentrate. The review done by Bargo *et al.* (2003) showed that fibre-based concentrates marginally increased DMI by 0.13 kg/d (DMI response range: -0.7 to 1.4 kg/d). It can be postulated that PKE inclusion in concentrate (20 and 40% inclusion level) sustained

milk production, due to increased pasture DMI. This hypothesis, however, cannot be tested due to averaged group DMI estimations used in the current study. Bargo *et al.* (2003) proposed that ruminal pH and pasture digestion would increase when starch-based concentrates are replaced with fibre-based concentrates, hence resulting in higher DMI. This was, however, not the case in the rumen fermentation study (Chapter 5, Section 5.3.1 and 5.3.4). Therefore the increased pasture DMI hypothesis should be interpreted with caution.

4.3.3 Concentrate refusals

The morning, afternoon and total daily concentrate refusals of each treatment are represented in Table 4.5. The total daily concentrate refusals did not differ ($P > 0.05$) between treatments. There are two potential reasons for the refusals of the concentrates; concentrates were fed in a meal form in the current study where the cows are normally accustomed to pelleted concentrates, and the low palatability of PKE could also contribute to the concentrate refusals of the low PKE and high PKE treatment groups. It can be suggested that a longer adaptation period would have overcome the concentrate refusals or the time spent in the milking parlour could be increased, however this is not economically viable. The concentrate refusals measured in the current study are of little importance as it was measured on an 'as is' basis and not on a DM basis. Milk yield was sustained in the low PKE and high PKE treatment groups, regardless of the amount of concentrate refusals.

4.3.4 Effect of palm kernel expeller supplementation on milk composition

The milk composition (fat, protein, lactose, SCC and MUN) of cows on each treatment is presented in Table 4.5.

4.3.4.1 Milk fat

The mean milk fat content and milk fat yield were similar for cows on the three treatments ($P > 0.05$). An increased milk fat percentage has been reported by previous authors when fibre-based concentrates replaced starch-based concentrates fed to dairy cows grazing ryegrass pasture ($P < 0.05$; Sayers *et al.*, 2003; Meeske *et al.*, 2009; Lingnau, 2011). On the contrary, most grazing studies reported no change in milk fat content when fibre-based concentrates replaced starch-based concentrates ($P > 0.05$; Meijs, 1986; Khalili & Sairanen, 2000; Delahoy *et al.*, 2003; Gehman *et al.*, 2006). The results of the current study concur to the results obtained

by Carvalho *et al.* (2006) who found no difference in milk fat content when SEPKC was included up to 15% in a TMR ($P > 0.05$).

The milk fat values obtained in the current study were higher than reported in previous grazing studies replacing starch-based concentrate with fibre-based concentrate (Meijs, 1986; Khalili & Sairanen, 2000; Delahoy *et al.*, 2003; Sayers *et al*., 2003; Gehman *et al.*, 2006). This is because most of these studies made use of larger breed dairy cows (Holstein/Dutch Friesian), which have naturally a lower milk fat content compared to Jersey cows. The reason for the higher milk fat content obtained in the current study (4.62, 4.65 and 4.66%) compared to that of Meeske *et al.* (2009) (3.66, 4.03 and 4.41%) could be due to the higher NDF level (49.4% DM) of the high quality pasture grazed in the current study.

4.3.4.2 Milk protein

There were no differences found in milk protein content and milk protein yield between cows on the three treatments ($P > 0.05$). Meijs (1986), Khalili & Sairanen (2000), Meeske *et al.* (2009) and Lingnau (2011) also reported similar milk protein content from grazing cows supplemented with either starch-based or fibre-based concentrates ($P > 0.05$). However, Delahoy *et al.* (2003) reported lower milk protein values from grazing cows supplemented with non-forage fibre sources (beet pulp and soybean hulls) compared to ground corn supplementation ($P < 0.05$). Gehman *et al.* (2006) also reported lower milk protein values for grazing cows supplemented with citrus pulp and molasses compared to corn supplementation. A review done by Bargo *et al.* (2003) summarised that milk protein content was reduced by -0.06 percentage units with fibre-based concentrates compared to starch-based concentrates, with a milk protein response range from -0.21 to 0.05 percentage units. However, Bargo *et al.* (2003) also reported that there is not conclusive evidence to make general conclusions regarding starch-based *vs*. fibre-based concentrates supplemented to grazing cows due to the small amount of studies that involve these comparisons. The results of the current study concur to the results obtained by Carvalho *et al.* (2006) who found no difference in milk protein content when SEPKC was included up to 15% in a TMR ($P > 0.05$).

Table 4.5 The mean milk yield, 4% fat corrected milk (FCM), energy corrected milk (ECM), milk components (fat, protein, lactose, somatic cell count (SCC) and milk urea nitrogen (MUN)), milk fat and protein yield, as well as the concentrate refusals of Jersey cows (n = 16) fed 6 kg (as is) concentrate per day, which included either 0% (control), 20% (low PKE) or 40% PKE (high PKE) inclusion, respectively, grazing kikuyu/ryegrass pasture

Parameter[1]	Treatment concentrate[2]			SEM[3]	P-value
	Control	Low PKE	High PKE		
Milk Yield (kg/cow/d)	21.32	21.26	20.71	0.68	0.78
4% FCM (kg/cow/d)	23.24	23.22	22.71	0.69	0.83
ECM (kg/cow/d)	24.82	24.67	24.18	0.72	0.80
Milk composition					
Milk Fat (g/kg)	46.27	46.53	46.62	1.33	0.98
Milk Protein (g/kg)	35.39	34.55	34.95	0.51	0.52
Milk Lactose (g/kg)	47.30^{a}	46.65^{ab}	45.77^{b}	0.34	0.01
MUN (mg N/dl)	17.67	18.63	19.09	0.50	0.14
SCC (x 10^3/ml)	166.29	162.29	162.65	33.44	0.99
Yield of milk constituents					
Milk Fat Yield (kg/cow/d)	0.98	0.98	0.96	0.03	0.89
Milk Protein Yield (kg/cow/d)	0.75	0.73	0.72	0.02	0.64
Concentrate refusals (as is)					
AM refusals (%)	3.4	3.1	9.2	2.25	0.12
PM refusals (%)	6.0	5.4	11.2	2.63	0.24
Total daily refusals (%)	9.4	8.5	20.5	2.43	0.17

[1]FCM – fat corrected milk; ECM – energy corrected milk; SCC – somatic cell count; MUN – milk urea nitrogen; N – nitrogen; AM – morning; PM – afternoon
[2]Control – concentrate containing 0% PKE; Low PKE – concentrate containing 20% PKE; High PKE – concentrate containing 40% PKE; PKE – palm kernel expeller
[3]SEM – standard error of the mean
[a,b] means in the same row with different superscripts differ (P < 0.05)

4.3.4.3 Milk lactose

The milk lactose content was higher for cows supplemented with the control treatment than for cows supplemented with the high PKE treatment ($P < 0.05$). These milk lactose values falls in the region of 4.7% as reported by Gibson (1989) for Jersey cows, whereas the milk lactose content of cows receiving the high PKE treatment are slightly lower than that of the specified region. Khalili & Sairanen (2000) reported a higher milk lactose yield for cows supplemented with barley (starch-based) than for cows supplemented with oats, wheat bran and beet pulp (fibre-based) ($P < 0.05$), however this could possibly be attributable to increased milk yield ($P < 0.05$), with no alteration in milk lactose content ($P > 0.05$). Carvalho *et al.* (2006) found a tendency for SEPKC inclusion (0, 5, 10 and 15%) in a TMR to increase the lactose content of milk ($P < 0.10$).

Milk lactose percentage varies the least compared to other milk components, irrespective to cow breed or diet changes (Sutton, 1989; Kennelly & Glimm, 1998). Therefore a difference in milk lactose content between treatments was not expected. According to Welper & Freeman (1992) milk lactose content is affected by change in SCC or udder health. This was, however, not the case in the current study as SCC was not affected by treatment ($P > 0.05$; Section 4.3.3.5). Further research should be done to fully understand milk lactose content as effected by various feed sources, because the statements made by Sutton (1989) and Jenkins & McGuire (2006) in the literature review does not agree with the results obtained in the current study and with the findings of Carvalho *et al.* (2006).

4.3.4.4 Milk urea nitrogen

There were no differences in the mean MUN concentration between the treatments ($P > 0.05$). This is in agreement with results from several published grazing studies supplementing either starch-based or fibre-based concentrates to dairy cows (Khalili & Sairanen, 2000; Meeske *et al.*, 2009; Lingnau, 2011). Only one study was found who reported a lower MUN concentration for cows supplemented with a high fibre concentrate containing citrus pulp compared to a low fibre-based concentrate ($P < 0.05$; Gehman *et al.*, 2006).

Roseler *et al.* (1993) suggested that variation in MUN concentration is related to the protein to energy (CP:ME) ratio of the diet consumed. Milk urea nitrogen concentration increases as this ratio increases. Kohn (2007) recommended MUN

concentrations between 8 to 12 mg/dl under typical TMR production conditions. The MUN concentrations in the current study are well above this range, indicating a general excess of N in the cow based on the animal's milk yield (Kohn, 2007). The high CP:ME ratio of the grazed pasture (1.87 ± 0.24:1) (Table 3.2) could contribute to the high MUN concentrations obtained in the current study. It is generally accepted, however, that acceptable MUN ranges for fertilised pasture-based dairy systems are higher than that of cows on TMR systems. This is supported by the findings of Trevaskis & Fulkerson (1999) who found a positive correlation between MUN and the ratio of N to water soluble carbohydrates in pasture, and by the results from published studies (Bargo *et al.*, 2003; Meeske *et al.*, 2009; Lingnau, 2011). To summarise, the MUN concentrations of the current study indicates that dietary protein was not limiting, but rather fed in excess to some extent, but still within an acceptable range for pasture-based systems.

4.3.4.5 Somatic cell count

The mean SCC was similar for each treatment (P > 0.05). These values obtained during the current study were exceptionally acceptable and are well under the specified value of 300 x 10^3 cells/ml milk, which is indicative of subclinical mastitis and considered to be abnormal (De Villiers *et al.*, 2000). No response in SCC was expected due to the differences in treatments.

4.3.5 Effect of palm kernel expeller supplementation on body weight and body condition score

Body weight and BCS parameters are presented in Table 4.6. The BW and BCS did not differ between treatments (P > 0.05). These results are similar to that found by several authors who conducted grazing studies where starch-based concentrates were compared with fibre-based concentrates (Sayers *et al.*, 2003; Meeske *et al.*, 2009; Lingnau, 2011). Bargo *et al.* (2002a) stated that BW is not subject to change in such a short study period as would comprise a feeding study.

This indicates that PKE supplementation has little effect on BW change or BCS change of lactating dairy cows grazing kikuyu/ryegrass pasture. It can be postulated that cows did not lose BW or BCS at the expense of maintaining milk yield in the low and high PKE treatment groups, therefore the allocated pasture and concentrate provided sufficient energy to sustain milk yield.

Table 4.6 The mean before, after and change in body weight (BW) and body condition score (BCS) of Jersey cows (n = 16) fed 6 kg (as is) concentrate per day, which included either 0% (control), 20% (low PKE) or 40% PKE (high PKE) inclusion, respectively, grazing kikuyu/ryegrass pasture

Parameter[1]	Treatment concentrate[2]			SEM[3]	P-value
	Control	Low PKE	High PKE		
Body weight					
BW before (kg)	375.7	363.0	373.3	9.96	0.64
BW after (kg)	412.2	396.3	412.4	10.80	0.49
BW change (kg)	+36.5	+33.3	+39.2	2.85	0.36
Body condition score					
BCS before (scale 1 to 5)	2.44	2.31	2.31	0.08	0.41
BCS after (scale 1 to 5)	2.59	2.50	2.47	0.10	0.68
BCS change (scale 1 to 5)	+0.16	+0.19	+0.16	0.06	0.90

[1]BW – body weight; BCS – body condition score
[2]Control – concentrate containing 0% PKE; Low PKE – concentrate containing 20% PKE; High PKE – concentrate containing 40% PKE; PKE – palm kernel expeller
[3]SEM – standard error of the mean

4.4 Conclusion

Partial replacement of maize with 20 and 40% PKE in lactating dairy cow concentrates did not affect milk production, milk fat content, milk protein content, MUN or SCC. Neither the BW nor BCS change was affected by PKE supplementation. Producers, however, should be cautioned when including PKE at 40% in the concentrate due to the increased time spent by cows in the milking parlour and the low palatability of PKE, which could lead to lower concentrate intakes. If economics favour high inclusion rates, results from our study has shown that levels of 2.4 kg PKE/cow/day can be fed without impairing productivity.

CHAPTER 5

Effect of palm kernel expeller supplementation on the rumen environment of Jersey cows grazing kikuyu/ryegrass pasture

5.1 Introduction

The research study consisted of two distinct studies, namely a lactation production study and a rumen study using rumen-fistulated cows. The two studies were conducted in tandem. The rumen study will be described in this chapter and the lactation production study was described in Chapter 4. This study (rumen study) was conducted at the Outeniqua Research Farm situated near George in the Western Cape to determine the effect of different PKE inclusion levels in dairy concentrates for Jersey cows on the rumen environment. The lactating rumen-fistulated cows in this study grazed with the production study cows as one group utilising the same pasture. The cows from both studies were milked together according to their allocated treatment groups, however the milk data from the rumen-fistulated cows was not used. The production study was not provoked by any means during the duration of the rumen study.

5.2 Materials and methods

5.2.1 Location, climate and soil

See Section 3.2.1 of Chapter 3 for details regarding the location, climate and soil of this study.

5.2.2 Animal welfare

See Section 3.2.4 of Chapter 3 for details regarding animal welfare.

5.2.3 Duration of the study

Before the study commenced, cows were adapted for 7 d on the pasture with *ad libitum* access to PKE only. During this adaptation period PKE only was fed in feeding troughs on pasture and due to practical constraints all treatment cows had access to the PKE only. This was done to allow cows to become accustomed to the low palatable PKE. The study extended over a period of 60 d, divided into two data

collecting periods. The first period consisted of a 20 d adaptation period, where cows received allocated treatment concentrates in the dairy parlour, followed by an 8 d data collection period for the first treatment diet. Succeeding this, a second 20 d adaptation period was followed by an 8 d data collection period for the second treatment diet. As a result, cows received both diets during the progression of the rumen study.

5.2.4 Grouping of cows

Eight lactating rumen-fistulated cows from the Outeniqua Research Farm herd were used. The cows were randomly (random function in Microsoft Excel, 2010) allocated to the control (0% PKE) treatment group and to the high PKE (40% PKE) treatment group resulting in four rumen-fistulated cows for each of the control and high PKE treatment in a two period cross-over design. All cows were therefore subjected to the control and high PKE treatment concentrates. The cows have previously been fitted with cannulae (#1C Rumen Cannula) by Dr Dempsey de Lange using the Bar Diamond Cannulae Surgery technique (Bar Diamond Inc, P.O. Box 60, Parma, Idaho, USA). The rumen-fistulated cows strip grazed the kikuyu/Italian ryegrass pasture jointly with the production study cows as one group for 24 h per day except during milking times when they received concentrate supplementation in the milking parlour. The rumen-fistulated cows wore colored tags representing their allocated treatment group to facilitate in the separation process prior to milking. Cows from both the studies were milked together, however the milk data of the rumen-fistulated cows were not used for the production study.

5.2.5 Pasture and feed allocation

See Section 3.2.8 of Chapter 3 for details regarding the pasture allocation and see Section 4.2.5 of Chapter 4 for details regarding the treatment concentrate allocation.

5.2.6 Rumen data collection

Three rumen analytical methods were applied during the course of the 8 d data collecting period for each of the two cross-over periods. Firstly, ruminal pH was measured with indwelling pH loggers over a 4 d period; secondly, rumen fluid was extracted using a modified hand drain pump to determine ruminal VFA and NH_3-N concentrations, and pH was measured using a handheld pH meter; and lastly an *in*

situ study prolonged for 30 h with three removal intervals to determine DM_d, NDF_d and NDF k_d of the available kikuyu/ryegrass pasture affected by treatment.

5.2.6.1 Indwelling pH logging system

Ruminal pH was measured with pH-HR pH/temperature logging systems (TruTrack Data Logger, www.intech.co.nz). Each logging system was inserted into a flexible watertight capsule to minimise logger malfunction and any discomfort to the cow, while allowing the electrode probe maximum access to the rumen content. This custom-made capsule with logger was permanently mounted to a cannula plug (Figure 5.1), allowing it to be easily and securely fitted to a cow via the Bar Diamond #1C Rumen Cannula. A day prior insertion, the loggers were calibrated using the Omnilog Data Management Program (Version 1.64) with buffer solutions of pH 4, 7 and 9. Loggers were started on the Omnilog Program an hour prior insertion and the electrode probes were rinsed with distilled water before insertion. The loggers were inserted at 06:30 AM on Thursday and removed at 07:30 AM on Monday. The logging systems logged an average pH value in 10 min intervals over a 4 d period. After the completion of the logging period, the loggers were removed, data downloaded, and the loggers recalibrated following the same procedure as mentioned above. The data sets were reduced by condensing the 10 min intervals to 30 min intervals by taking the average of every three 10 min intervals. This was done by averaging the pH reading before, at and after the specified time, followed by calculating the mean over the four days. This was done for each cow. After the cross-over, the same procedures were followed and the same pH data logger was allocated to the same cow in order to reduce variation.

5.2.6.2 Rumen fluid sampling

Rumen fluid samples were extracted to determine the VFA and ruminal NH_3-N concentrations. Each cow was sampled three times on one day during each data sampling period. The sampling intervals commenced at 06:30 AM (1 h-post morning concentrate feeding), 13:30 PM (7 h-post morning or 2 h-pre afternoon concentrate feeding), and 20:30 PM (5 h-post afternoon or 9 h-pre morning concentrate feeding), respectively. Approximately 100 ml of rumen fluid was collected during each sampling interval from each cow using a customised hand drain pump (Figure 5.2). Rumen fluid was drawn with a 500 mm aluminium rod (5 mm in diameter), connected via an air tight sampling bottle with a hand drain pump, by inserting the full length of

the rod into the rumen, via a 5 mm hole in the rumen cannula plug, and moving the rod up and down in the rumen while pumping the rumen fluid out into the sampling bottle. A negative vacuum forms in the attached sampling bottle after each draw of the pump, allowing rumen fluid to enter freely. The rumen fluid collected from all eight rumen-fistulated cows was collected in separate sampling bottles labelled to represent each cow. Directly after collection, the samples were sealed air tight to avoid oxygen exposure and were placed in the shade to avoid volatility of the contents pending pH measurement. The pH of the samples was measured directly after extraction using a hand held pH logger (WTW pH340i pH meter/data logger attached with a WTW Sentix 41 pH electrode) and recorded. After pH measurement, the samples were sealed air tight and taken to the lab on sight pending filtration.

Rumen fluid samples were filtered through four layers of cheesecloth to remove solid particles. Two filtered rumen fluid samples were prepared for each cow. The one sample contained a 5:1 ratio of rumen fluid and 25% Ortho-phosphoric acid (H_3PO_3) solution pending VFA analyses, and the other sample was made up with a 6:1 ratio of rumen fluid and 50% Sulphuric acid (H_2SO_4) solution pending NH_3-N analyses. Sampling bottles labelled with the cow's identification, sampling interval, and sampling period were sealed air tight. The samples were immediately stored in a freezer at -20° C after preparation for later analyses at Nutrilab, University of Pretoria. Before analyses commenced the VFA and ruminal NH_3-N samples were thawed at room temperature (20° C). Samples were centrifuged, using a benchtop centrifuge (Rotofix 32A, Hettich Zentrifugen, Tuttlingen, Germany), for 10 min at 3000 rpm producing a *g*-force of 2522, after which the supernatant was removed and filtered through syringe filters with a 0.45 µm GHP (hydrophilic polypropylene) membrane (Pall South Africa (Pty) Limited, Birchwood Court, 43 Montrose Road, Vorna Valley, Midrand). The VFA samples were analysed using the Gas Chromatographic method (Broderick & Kang, 1980 modified; Webb, 1994) and the ruminal NH_3-N samples were analysed using catalysed phenol-hypochlorite and ninhydrin colorimetric procedures (Broderick & Kang, 1980).

5.2.6.3 *In situ* pasture degradability

An *in situ* nylon bag study was conducted to determine the DM_d, NDF_d and NDF k_d of the available kikuyu/Italian ryegrass pasture affected by different PKE inclusions in the concentrate. Eight kilograms (as is) of kikuyu/ryegrass herbage was

cut by hand at a stubble height of 30 mm. Pasture yield was accepted to be 1500 kg DM/ha which indicates that the pasture was at point of grazing, therefore allowing for a representative sample. The wet herbage was dried in brown paper bags at 60° C for 72 h (Botha, 2003), where after it was pooled. Dried samples were cut into 5 - 10 mm lengths (Taweel *et al.*, 2004) using sharp scissors and weighed into nylon bags (10 x 20 cm inner size; 53 µm pore size; Bar Diamond Inc, P.O. Box 60, Parma, Idaho, USA). A sample size to bag surface area ratio (Vanzant *et al.*, 1998) of 12.5 mg/cm^2 was obtained by weighing 5 g DM of the sample into each bag. Prior to weighing the sample into the bags, the bags were first dried at 50° C overnight, after which the weight was recorded (Sartorius L420P scale, with 0.001 g accuracy). The weight of each bag with sample was recorded, followed by closing each bag with a cable tie before recording the weight again, hence resulting in three recorded weights for each bag before incubation.

Rumen incubations were carried out using eight lactating rumen-fistulated Jersey cows (four cows representing the low PKE treatment group and four cows representing the high PKE treatment group). Sample nylon bags were incubated in the rumen for 6, 18, and 30 h to calculate the NDF k_d (Van Amburgh *et al.*, 2003). The sample nylon bags were inserted into the rumen at 14:00 PM (1.5 h-pre afternoon concentrate feeding) where after the first nylon bag removal commenced at 20:00 PM (3.5 h-post afternoon concentrate feeding), the second at 08:00 AM (2.5 h-post morning concentrate feeding) the following day and lastly the third at 20:00 PM (3.5 h-post afternoon concentrate feeding). Two bags were used for each time interval as duplicates to minimise the effect of the cow on degradation characteristics, resulting in six bags per cow. Three sample nylon bags per period, resulting in 6 nylon bags in total, were made up to represent the zero time point.

The receptacle and catcher technique was used, described by Cruywagen (2006), to facilitate in the incubation and removal of *in situ* nylon bags from the rumen. Following this technique, three bags were placed in one large opaque stocking leg (receptacle) and knotted in between to separate the bags from one another (Figure 5.3). To prevent the receptacle from floating on top of the rumen contents, a large glass marble was knotted in place at the bottom of the receptacle. Two receptacles connected to a cannula plug via its own catcher were placed in each cow. After incubation, the nylon bags were removed from the receptacle and

rinsed under running cold water for one minute where after it were preserved in a freezer at -20° C. This was done for each time interval removal.

Before washing, the frozen bags were left to thaw for 30 min in a Defy Twinmaid washing machine filled to one quarter with clean cold water. After thawing, the bags were washed with cold water for three consecutive 3 min cycles without spinning (gentle setting on washing machine). After each cycle, the water was drained and replaced with clean cold water. The bags were placed on a steel grid to drip dry for the removal of excess water, before the bags were dried at 55° C for 72 h. Bags were weighed individually and recorded using the exact scale as when weighed in. The zero time point bags were treated in the same manner as the other bags, excluding incubation. The DM content of the cut kikuyu/Italian ryegrass herbage used for the *in situ* study was determined before incubation. The *in situ* bag residues were removed and stored separately pending NDF analyses at UP Nutrilab (Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria). The NDF samples were analysed using the filter bag technique (ANKOM technology method 9: Filter bag technique, ANKOM^{2000} fibre analyser; Robertson and Van Soest, 1981).

Figure 5.1 Indwelling pH logging system used to measure ruminal pH in 10 minute intervals prior insertion into the rumen

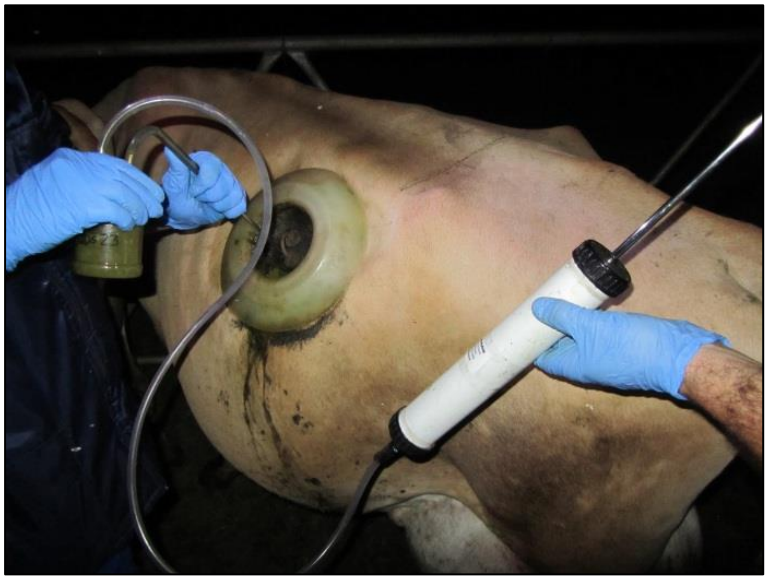

Figure 5.2 Customised hand drain pump used to collect rumen fluid samples via the cannula plug

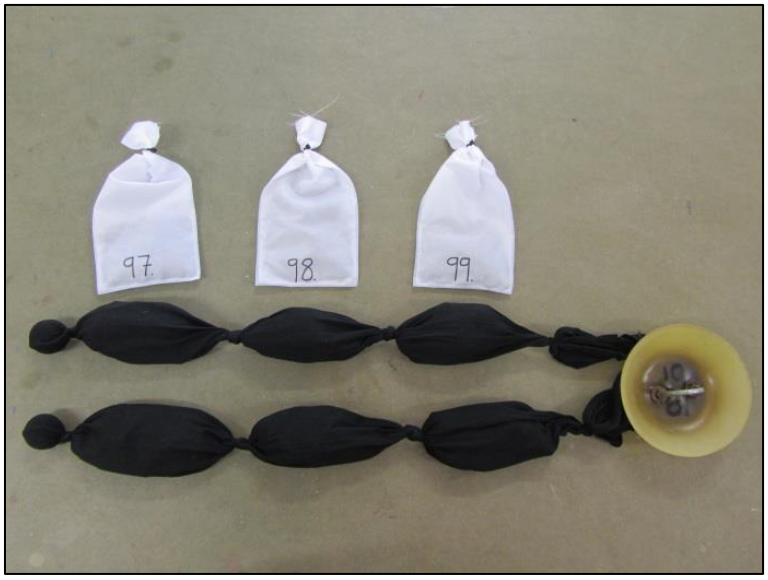

Figure 5.3 The final product of the receptacle and catcher technique prior insertion into the rumen and a presentation of the finalised nylon bags used in this study

5.2.7 Statistical analysis

The rumen study data were analysed statistically using the GLM model (Statistical Analysis Systems Institute, 2012) in a cross-over design, which ensures that both treatments are present in both periods. Repeated measures analysis of variance (ANOVA) with the GLM model was used for repeated time effects. Means and standard error were calculated and significance of difference ($P \leq 0.05$) between means was determined by Fischer's test (Samuels, 1989). A tendency for differences between treatments was declared at $P < 0.10$. The linear model used is described by the following equation:

$$Y_{ik} = \mu + T_i + P_k + e_{ik}$$

Where Y_{ik} = variable studied during the period
μ = overall mean of the population
T_i = effect of the i^{th} treatment
P_k = effect of the k^{th} period
e_{ik} = random error associated with each Y

5.3 Results and discussion

5.3.1 Effect of palm kernel expeller supplementation on ruminal pH

Table 5.1 represents the mean, maximum, minimum and median ruminal pH values, and Figure 5.4 represents the mean diurnal ruminal pH fluctuations per time interval averaged over four days measured by indwelling pH logging systems during the rumen study period.

There were no differences in mean, maximum, minimum and median ruminal pH values between treatments measured over four days with indwelling pH loggers ($P > 0.05$; Table 5.1). A difference, however, was observed at the 16:30 PM time interval ($P < 0.05$), 6.41 and 6.22, respectively (Figure 5.4). The latter was probably due to cow and logger variability and does not hold any significant biological importance, as there were no differences observed between treatments at the other time intervals. The highest ruminal pH values for cows on both treatments were observed just before concentrate feeding, especially before the morning feeding, while the lowest values were observed around 4.5 – 5 h post-feeding. This is in agreement with Bargo *et al.* (2002b) who reported that ruminal pH is highest pre-concentrate feeding and lowest post-concentrate feeding, more specifically 2 – 5 h post-concentrate feeding (Nordlund & Garrett, 1994; Nocek, 1997; Cajarville *et al.*, 2006). None of the treatment concentrates fed in the current study resulted in cows suffering from acute ruminal acidosis or subacute ruminal acidosis, which are defined by pH < 5 and pH < 5.6, respectively, based on the mean and minimum pH values (Owens *et al.*, 1996). The mean ruminal pH of each treatment falls well within the range of 6.0 to 6.9 that stimulates optimal ruminal fibre digestion (Pitt *et al.*, 1996; Kolver *et al.*, 1998a).

The extent of pH fluctuation was similar for cows on both treatments and the pH decreased steadily in two cyclic pH drops in the ruminal pH profile. This indicates a normal diurnal pH fluctuation. The decline in pH observed post-concentrate feeding, is as a result of the presence of RFC in the concentrates (Dixon & Stockdale, 1999). The ruminal pH for cows on both treatments was never below 5.0, where complete cessation of ruminal fibre digestion occurs (Mould *et al.*, 1984). It is evident in Figure 5.4 that the pH of both treatments was never below 5.8. The pH of the Control and High PKE treatment cows remained below 6.2 for 3.5 and 6.5 h, respectively, and

below 6.0 for 0 and 2 h, respectively. Hoover (1986) states that when ruminal pH falls for a short duration in the 5.8 to 6.2 range, a moderate brief reduction in ruminal fibre digestion is likely to occur. The short duration that the pH remained under 6.2 and 6.0 in the current study indicates that the combination of the pasture and treatment concentrates resulted in effective buffering capacity to overcome perpetual low pH values.

Manual pH readings were recorded every time rumen fluid was collected for ruminal VFA and NH_3-N analyses at 06:30, 13:30 and 20:30 (Table 5.2). There were no differences between treatments in pH at any of the three time intervals or in mean pH (Table 5.2). This coincides with the results obtained by the indwelling pH logging system. However, the pH values differ substantially at the specified time intervals between the two pH measuring systems (indwelling and manual). This could be due to the fact that the manual samples were exposed to air while pH readings were taken and another reason could be that the manual samples were not taken in the same place as where the indwelling loggers were positioned in the rumen. Colman *et al.* (2010) stated that pH varies considerably at different locations in the rumen and during the day. Regardless of this, ruminal pH was not affected by treatment in either one of the pH measuring systems.

Table 5.1 The mean, maximum, minimum and median ruminal pH (indwelling loggers) of Jersey cows (n = 8) fed 6 kg (as is) concentrate per day, which included either 0% (control) or 40% PKE (high PKE) inclusion, respectively, grazing kikuyu/ryegrass pasture

Parameter[1]	Treatment concentrate[2]		SEM[3]	P-value
	Control	High PKE		
Mean pH	6.42	6.33	0.08	0.48
Max pH	6.82	6.79	0.10	0.85
Min pH	6.04	5.93	0.09	0.44
Median pH	6.40	6.31	0.08	0.46

[1]Max – maximum; Min – minimum
[2]Control – concentrate containing 0% PKE; High PKE – concentrate containing 40% PKE; PKE – palm kernel expeller
[3]SEM – standard error of the mean

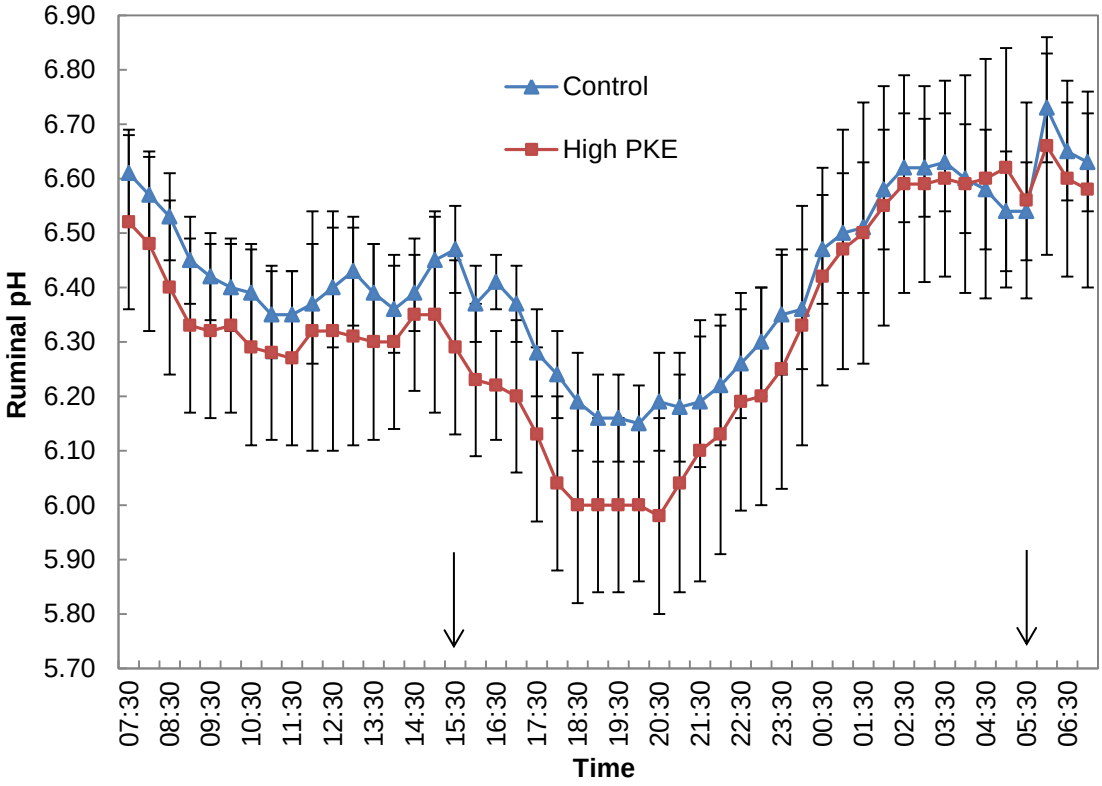

Figure 5.4 The mean ruminal diurnal pH (indwelling loggers) per time interval of Jersey cows (n = 8) fed 6 kg (as is) concentrate per day, which included either 0% (control) or 40% PKE (high PKE) inclusion, respectively, grazing kikuyu/ryegrass pasture. Arrows indicate when concentrate was fed (error bars indicate SEM)

5.3.2 Effect of palm kernel expeller supplementation on ruminal volatile fatty acid profile

The ruminal parameters such as VFA concentrations, ruminal NH_3-N concentrations and handheld pH measurements at three time intervals for cows receiving the control and high PKE treatments are represented in Table 5.2. The molar proportions of VFA's were not calculated, as the actual concentrations are preferred when analysing VFA data (Van Soest, 1982).

There were no differences between treatments in total VFA, acetic acid, butyric acid and valeric acid concentrations at any of the three time intervals, including the mean of the three time intervals. The propionic acid concentration of cows supplemented with the high PKE treatment was lower than that for cows supplemented with the control treatment, but only at the 13:30 time interval ($P < 0.05$). However, the propionic acid concentration also tended to be lower for cows on

Table 5.2 Mean volatile fatty acid (VFA) concentrations, ruminal ammonia nitrogen concentrations and handheld pH measurement in rumen fluid obtained at three time intervals from Jersey cows (n = 8) fed 6 kg (as is) concentrate per day, which included either 0% (control) or 40% PKE (high PKE) inclusion, respectively, grazing kikuyu/ryegrass pasture

Rumen parameter[1]	Time	Treatment concentrate[2]		SEM[3]	P-value
		Control	High PKE		
Total VFA (mmol/L)	06:30	112.9	102.7	4.09	0.13
	13:30	133.0	123.6	5.00	0.23
	20:30	116.3	128.6	4.81	0.12
	Mean	120.7	118.3	3.44	0.63
Acetic acid (mmol/L)	06:30	72.4	66.8	2.67	0.19
	13:30	84.8	80.6	2.97	0.35
	20:30	72.7	80.4	2.89	0.11
	Mean	76.6	75.9	2.09	0.82
Propionic acid (mmol/L)	06:30	21.8	19.4	0.73	0.06
	13:30	26.3[a]	23.0[b]	0.95	0.046
	20:30	24.6	25.9	0.88	0.31
	Mean	24.2	22.8	0.60	0.14
Acetic:Propionic acid ratio	06:30	3.39	3.49	0.04	0.17
	13:30	3.26[a]	3.53[b]	0.04	<0.01
	20:30	2.99[a]	3.19[b]	0.05	0.03
	Mean	3.22[a]	3.40[b]	0.03	<0.01
Butyric acid (mmol/L)	06:30	16.3	14.0	0.67	0.06
	13:30	19.0	16.9	0.99	0.17
	20:30	16.6	18.5	0.88	0.16
	Mean	17.3	16.5	0.67	0.43
iso-Butyric acid (mmol/L)	06:30	1.02	0.97	0.06	0.59
	13:30	1.17	1.22	0.07	0.64
	20:30	0.99[a]	1.28[b]	0.08	0.04
	Mean	1.06	1.16	0.06	0.29
Valeric acid (mmol/L)	06:30	1.39	1.46	0.13	0.71
	13:30	1.66	1.98	0.26	0.41
	20:30	1.54	2.40	0.35	0.14
	Mean	1.53	1.95	0.24	0.26
NH_3-N (mg/dl)	06:30	15.6[a]	12.2[b]	0.59	<0.01
	13:30	12.8	14.5	1.12	0.33
	20:30	13.0[a]	17.0[b]	0.53	<0.01
	Mean	13.8	14.6	0.59	0.39
Handheld pH	06:30	6.15	6.20	0.07	0.60
	13:30	5.76	5.77	0.04	0.88
	20:30	5.75	5.70	0.04	0.43
	Mean	5.89	5.89	0.03	0.89

[1]VFA – volatile fatty acid; NH_3-N – ammonia-nitrogen
[2]Control – concentrate containing 0% PKE; High PKE – concentrate containing 40% PKE; PKE – palm kernel expeller
[3]SEM – standard error of the mean
[a,b] means in the same row with different superscripts differ (P < 0.05)

the high PKE treatment at the 06:30 time interval ($P < 0.10$). In response to the lower ruminal propionic acid concentration of cows receiving the high PKE treatment, the mean acetic to propionic acid ratio of cows receiving the high PKE treatment, as well as at the 13:30 and 20:30 time interval were lower than that of cows receiving the control treatment ($P < 0.05$).

Van Vuuren *et al.* (1986) and Sayers *et al.* (2003) found that supplementation had no effect on total VFA concentration of cows grazing ryegrass pasture when starch-based concentrates were replaced by fibre-based concentrates, regardless of ruminal pH reductions (Carruthers & Neil, 1997; Carruthers *et al.*, 1997). This is supported by Seymour *et al.* (2005) who found that ruminal pH is negatively related to total VFA concentration in rumen fluid. This is in agreement with the total VFA results obtained in the current study. The mean total VFA concentration obtained for both treatments is very similar to the mean total VFA concentration of 120.9 mmol/L (range: 90.3 to 151.4 120.9 mmol/L) compiled by Bargo *et al.* (2003) from ten studies, where cows received energy supplementation grazing pasture.

Acetic, propionic and butyric acid are the three principle VFA's of the rumen (Seymour *et al.*, 2005), whereas acetic acid being the dominant VFA in the rumen of cows (Ishler *et al.*, 1996), as seen in Table 5.2. Sayers *et al.* (2003) found that fibre-based concentrates increased the concentrations of acetate and butyrate, and decreased the concentration of propionate, whereas Khalili & Sairanen (2000) reported no change in the principle VFA's. The principle VFA results obtained in the current study are in agreement with the results of Khalili & Sairanen (2000). Seymour *et al.* (2005) found that butyric acid was positively correlated to milk yield but negatively correlated to milk fat. A study done by Lingnau (2011) found that the concentration of butyric acid decreased when a low starch concentrate replaced a high starch concentrate. Therefore, a decrease in butyric acid concentration in the rumen may have been expected when feeding the high PKE concentrate, although this did not occur in the current study.

The acetic to propionic acid ratio in rumen fluid is positively correlated with milk fat (g/kg) (Seymour *et al.*, 2005). An increase in milk fat content would have been expected in the high PKE treatment as result of the higher acetic to propionic acid ratio for cows on the high PKE treatment compared to cows on the control treatment. Such an increase in the acetic to propionic acid ratio would likely have been ascribed

to the high NDF content of the high PKE concentrates, 295 g/kg DM (Sairanen *et al.*, 2006). However, this was not the case in the current study (Section 4.3.3.1, Chapter 4). The NDF content of non-forage fibre sources, such as PKE, have a small mean particle size, low lignin content and a high fibre digestibility, therefore resulting in a low peNDF content (Bradford & Mullins, 2012). Physical effective NDF is strongly associated with milk fat yield and ruminal pH, as demonstrated by Zebeli *et al.* (2008a). This is supported by Allen (1997), who reported a positive relationship between ruminal pH and milk fat percentage. Results, therefore suggest that the similarity obtained in milk fat content between cows on the control and high PKE treatments ($P > 0.05$), are due to a lack of peNDF content in the PKE included in the concentrates and due to no differences found in the relative high ruminal pH between treatments ($P > 0.05$). This is only speculative, as peNDF was not properly measured during our study. The acetic to propionic acid ratios of all treatments, however, were higher than the value of 2:1 that was suggested as a threshold for milk fat depression (Erdman, 1988).

Jenkins & McGuire (2006) found that milk protein increased when cows were fed a feed source high in RFC. This is as a result of increased ruminal propionate and microbial protein production. Therefore, it is expected that milk protein will stay unchanged when cows receive a high fibre diet which is low in RFC. In the current study, the mean propionic acid concentration (Table 5.2) as well as the milk protein content (Table 4.5) did not differ between treatments.

The milk yield results coincide with the results obtained from the VFA profile of the rumen, specifically butyric and propionic acid. Milk yield is positively correlated with rumen concentrations of butyric acid followed by propionic acid (Seymour *et al.*, 2005) and since there were no increases in butyric or propionic acid concentrations for cows receiving the high PKE treatment ($P > 0.05$; Table 5.2), similar milk yields were predictable. The total VFA concentration for cows on the high PKE and control concentrates also did not differ, supporting the results obtained.

The ruminal *iso*-butyric acid concentration of cows receiving the high PKE treatment was higher only at the 20:30 time interval compared to that of cows receiving the control treatment ($P < 0.05$). This could be ascribed to cow and logger variability and does not hold any significant biological importance, as there were no differences observed between treatments at the other time intervals.

5.3.3 Effect of palm kernel expeller supplementation on ruminal ammonia nitrogen profile

The ruminal NH_3-N (mg/dl) concentrations collected at three time intervals for cows supplemented with the control and high PKE treatments are presented in Table 5.2.

There were no differences in mean ruminal NH_3-N concentration between cows receiving the control and high PKE treatments, respectively ($P > 0.05$). At 06:30, cows on the high PKE treatment had a lower ruminal NH_3-N concentration (12.2 mg/dl) compared to cows receiving the control treatment (15.6 mg/dl; $P < 0.05$), however at 20:30 the opposite occurred; cows receiving the control treatment had a lower ruminal NH_3-N concentration (13.0 mg/dl) compared to cows receiving the high PKE treatment (17.0 mg/dl; $P < 0.05$). There were no differences in ruminal NH_3-N concentration at 13:30 between treatments ($P > 0.05$). It is difficult to interpret these differences, because ruminal NH_3-N was only measured at three time intervals whereas a 24 h cycle would have indicated a better pattern of ruminal NH_3-N variation. It could also be hypothesized that the discrepancies observed in the ruminal NH_3-N concentrations were as a result of the difference in CP degradability of PKE and soybean oilcake. According to Bargo *et al.* (2002b) there are two daily peaks of ruminal NH_3-N concentration corresponding to ingestion of high CP pasture after receiving concentrate, as such it can be postulated that the control group cows ingested more pasture post morning milking (06:30) than the high PKE group. This hypothesis could not be tested, because the individual pasture intake per cow was not measured. The highest NH_3-N concentration (17.0 mg/dl) for cows on the high PKE treatment was observed at 20:30 in response to the lowest pH (5.97) that was also observed at 20:30 for cows on the high PKE treatment. This is in agreement with Cajarville *et al.* (2006) who found that the maximum NH_3-N concentration occurs at the minimum ruminal pH. The increased ruminal NH_3-N for the high PKE treatment at 20:30 may reflect recycling of N to the rumen to maintain bacterial N requirements (Robinson, 1983). This was, however, not the case for cows supplemented with the control treatment, where the highest NH_3-N concentration (15.6 mg/dl) for cows on the control treatment was observed at 06:30, where the pH was high (6.60).

The NH_3-N concentrations of the current study were well above 5 mg/dl as stated by Satter & Slyter (1974) for maximum microbial protein synthesis, and well

within the range of 8.5 to 30 mg/dl reported by McDonald *et al.* (2002) for improved microbial protein synthesis, digestibility and feed intake. This indicates that none of the treatment concentrates were deficient in protein and that microbial growth was not restricted, therefore no reductions in fibre degradation were expected. The mean NH_3-N concentration obtained from cows on both treatments was similar to the mean NH_3-N concentration of 18.3 mg/dl (range: 8.7 to 32.2 mg/dl) compiled by Bargo *et al.* (2003) from ten studies, where cows received energy supplementation grazing pasture.

5.3.4 Effect of palm kernel expeller supplementation on *in situ* pasture degradability

The *in situ* DM_d, NDF_d and NDF k_d of the kikuyu/ryegrass pasture of cows affected by treatment at three incubation periods are represented in Table 5.3.

There were no differences in estimated DM_d, NDF_d or NDF k_d at all three incubation times as well as in the mean NDF k_d between cows on the control and high PKE treatments ($P > 0.05$). The high DM_d values obtained at the 30 h incubation period for cows receiving the control (87.48%) and high PKE (89.70%) treatments corresponds to the high IVOMD value (80.22%, Table 3.2) obtained for the grazed kikuyu/ryegrass pasture. The high DM_d and NDF_d values where expected, due to the high quality of the pasture in the current study (Table 3.2).

Beauchemin (1991) found that an increase in fibre concentration in the diet resulted in an increase in microbial digestion of forage *in sacco*, as indicated by a greater extent of DM and NDF degradation and an increased rate of DM degradation. However the results in the current study are in agreement with the findings of Sayers *et al.* (2003), who found no effect on *in situ* ruminal digestion of ryegrass by replacing a starch-based concentrate with a fibre-based concentrate. Lingnau (2011) also found that by replacing a high starch concentrate supplement with a low starch concentrate supplement to cows on pasture did not improve the *in situ* degradability of pasture. Bargo *et al.* (2002a) found that the degradation rate of pasture was decreased only when high levels (>8 kg DM/d) of corn-based concentrates were fed to cows. The reason why no enhancements in ruminal forage degradation occurred in cows receiving the high PKE treatment can be hypothesised due to the fact that there were no differences in ruminal pH (Figure 5.4) between cows receiving the control and high PKE treatments ($P > 0.05$). This hypothesis is

supported by Beauchemin (1991) who reported that the enhancement of ruminal forage degradation may be related to increased pH of ruminal fluid which improves the rumen conditions for cellulolytic microorganisms to thrive. It can be summarised that the higher NDF level of the high PKE concentrate used in the current study did not improve the cellulolytic and fibrolytic micro-organism activity in the rumen significantly.

Table 5.3 The *in situ* dry matter disappearance, neutral detergent fibre disappearance and neutral detergent fibre disappearance rate of the available kikuyu/ryegrass pasture at three incubation periods from Jersey cows (n = 8) fed concentrate at 6 kg (as is) per day per cow, which included either 0% PKE (control) or 40% PKE (high PKE) inclusion

Parameter[1]	Incubation period (h)	Treatment concentrate[2]		SEM[3]	P-value
		Control	High PKE		
DM_d (%)	6	53.38	55.37	2.91	0.65
	18	78.52	80.79	1.80	0.41
	30	87.48	89.70	1.12	0.21
NDF_d (%)	6	29.75	32.45	3.37	0.59
	18	65.05	67.92	2.76	0.49
	30	79.49	82.85	1.82	0.24
NDF K_d (%/h)	6	7.79	7.62	0.73	0.88
	18	8.34	8.36	0.54	0.98
	30	8.66	9.03	0.32	0.44
	Mean	8.26	8.34	0.44	0.91

[1]DM_d – dry matter disappearance; NDF_d – neutral detergent fibre disappearance; NDF k_d – rate of neutral detergent fibre disappearance
[2]Control – concentrate containing 0% PKE; High PKE – concentrate containing 40% PKE; PKE – palm kernel expeller
[3]SEM – standard error of the mean

5.4 Conclusion

The inclusion of PKE, at 40% inclusion level, in concentrate for Jersey cows did not affect the ruminal VFA concentrations, NH_3-N concentration, pasture *in situ* DM_d, NDF_d or NDF k_d, or the rumen fluid pH ($P > 0.05$) when compared to cows receiving the control diet. The acetic to propionic acid ratio was higher for the high PKE treatment cows ($P < 0.05$); this could lead to a higher milk fat percentage, but was not observed in this study. Results therefore suggest that a 20% inclusion level of PKE would not affect ruminal fermentation patterns in a different way than the 40% inclusion level or the control diet.

No adverse effects of treatment concentrates on cow health were observed in this study, but the short-term duration of the study did not allow for any conclusions with regard to PKE in concentrate effects on cow health. The constant rumen parameters obtained in the current study indicate that the rumen environment was healthy at all times for both the treatments. Further comparisons involving PKE inclusions in dairy concentrates and starch-based and fibre-based concentrates fed to grazing cows would be of interest.

CHAPTER 6

Economical evaluation

The net daily and monthly profit of each treatment concentrate was compared to each other as represented in Table 6.1. The net daily and monthly profit only represents the income over feed cost and does not take any labour, machinery or any other farm related costs into account. Feed price was the only variable between treatments; all other factors were assumed similar and would not influence the economic analysis.

The herd size for the calculations consisted of 280 cows in milk, which is the average number of cows per producer in the Western Cape. Milk price is based on milk composition (milk fat %, milk protein %, and SCC). As there were no differences ($P > 0.05$) observed between the milk yield or the milk composition of the three treatment groups, the milk yield and milk price obtained for the control treatment group (21.3 kg/cow/day, R 3.74) was used over all three treatment groups. The average PKE cost from January 2012 to September 2012 was obtained from Pieter Brönn (Intelact (Pty) Ltd, Eastern Cape, pbronn@farmvision.co.za), the average feed cost from January 2012 to September 2012 was obtained from NOVA feeds, the milk price was obtained from Nestlé in September 2012, and the pasture cost was obtained from Outeniqua Research Farm in September 2012. The PKE cost included a transport fee of R 250/t in bulk from Port Elizabeth (Eastern Cape, RSA) to George (Western Cape, RSA).

In conclusion, the economical evaluation from this study illustrated that the high PKE treatment group resulted in the highest net profit margin over feed cost, followed by the low PKE treatment group, at a PKE:maize price ratio of 0.86. The replacement of higher cost maize and soybean oilcake by a lower cost PKE decreased feed cost. The possibility of replacing maize with PKE and the savings associated with the change is subject to maize and PKE price. Both the 20 and 40% PKE inclusion showed to be an economical prospect, because the farmer/feed company can save on the cost of the protein source. It is up to the farmer/feed company to calculate their own breakeven scenario when PKE is considered to be included in a dairy concentrate.

Table 6.1 Milk price according to milk composition, feed cost, and pasture cost for three concentrate treatments with different palm kernel expeller inclusions

Parameter[1]	Treatment concentrate[2]		
	Control	Low PKE	High PKE
Milk Yield (kg/cow/d)	21.3	21.3	21.3
Milk Price (R/L)	R 3.74	R 3.74	R 3.74
Milk Income (R/cow/d)	R 79.66	R 79.66	R 79.66
Milk Income (R/herd/d)	R 22 305.36	R 22 305.36	R 22 305.36
Decrease in daily income (R/herd/d)	R 0.00	R 0.00	R 0.00
Maize price (R/t)	R 2 580.00	R 2 580.00	R 2 580.00
PKE price (R/t)	R 0.00	R 2 225.00	R 2 225.00
Soybean Oilcake Price (R/t)	R 4 400.00	R 4 400.00	R 4 400.00
PKE:Maize price ratio	0.00	0.86	0.86
Feed Price (R/t)	R 3 449.00	R 3 277.00	R 3 100.00
Feed Price (R/cow/d)	R 20.69	R 19.66	R 18.60
Feed Price (R/herd/d)	R 5 794.32	R 5 505.36	R 5 208.00
Decrease in daily input cost (R/herd/d)	R 0.00	R 288.96	R 586.32
Pasture Price (R/kg)	R 1.00	R 1.00	R 1.00
Pasture Price (R/cow/d)	R 9.00	R 9.00	R 9.00
Pasture Price (R/herd/d)	R 2 520.00	R 2 520.00	R 2 520.00
Decrease in daily input cost (R/herd/d)	R 0.00	R 0.00	R 0.00
Margin over feed cost (R/herd/d)	R 13 991.04	R 14 280.00	R 14 577.36
Margin over feed cost (R/herd/month)	R 426 726.72	R 435 540.00	R 444 609.48
Increased margin over feed cost compared to control (R/herd/d)	R 0.00	R 288.96	R 586.32
Increased margin over feed cost compared to control (R/herd/month)	R 0.00	R 8 813.28	R 17 882.76

[1]Herd – 280 cows; R – South African Rand; PKE – palm kernel expeller; d – day; t – ton
[2]Control – concentrate containing 0% PKE; Low PKE – concentrate containing 20% PKE; High PKE – concentrate containing 40% PKE

CHAPTER 7
Critical evaluation

7.1 Pasture and concentrate

Pasture intake estimation: The RPM was used in combination with a regression, which was specifically designed for the paddock utilised in this study, to determine pasture allowance and pasture intake. It is however well known that this technique is inaccurate in determining pasture intake. One of the reasons for this inaccuracy is the fact that a herd average is used rather than an individual measurement for each cow. On the contrary, the RPM is a valuable tool for determining pre- and post-grazing heights, hence stocking rate. Intake measurement was not the main focus of the study. The measurement of individual intake would have added value to our study. More research is needed on practical alternatives to estimate DMI of cows on pasture.

Concentrate refusals: In this study cows were adapted for 7 days on the pasture with *ad libitum* access to PKE followed by 14 days adaptation receiving allocated treatment concentrate. Palm kernel expeller has a low palatability; therefore extended adaptation periods could be debated.

7.2 Rumen Study

Indwelling pH loggers: The indwelling pH loggers used in this study presented a calibration challenge; long hours were expended in calibrating these pH loggers. It could be debated that the size and shape of the loggers could further be improved to overcome the occasional bump to the logger caused by the milking parlour bale and nearby cows. This was because the pH loggers jutted slightly from the rumen. However, the pH loggers were functional and reliable pH data was obtained.

Rumen fluid and handheld pH sampling intervals: Only three time intervals were used for rumen sample collections (06:30 AM, 13:30 PM and 20:30 PM). Perhaps four sampling time intervals, evenly dispersed over 24 h, could be used to establish a trend in the ruminal VFA concentrations and NH_3-N levels, but this was not the purpose of the study. The purpose of the study was to determine the effect of the concentrate on the designated rumen parameters. Implementing more sampling time intervals marginally before and after concentrate intake, would perhaps describe the effect of the concentrate on the rumen parameters more accurately.

Rumen sampling area for rumen fluid: The technique used to collect rumen fluid in this study, involves rumen fluid being collected from various areas in the rumen. This could cause sampling error, due to the fact that the rumen content is divided into pools which consist of different phases. Each of these pools could have different VFA and NH_3-N concentrations, and pH levels. Perhaps a standardised technique can be designed to target a specific region (pool) within the rumen to obtain homogeneous rumen fluid samples or to compare rumen fluid samples collected from different regions within the rumen.

REFERENCES

Abdullah, N. & Hutagalung, R.I., 1988. Rumen fermentation, urease activity and performance of cattle given palm kernel cake-based diet. Anim. Feed Sci. Tech. 20: 79-86.

Abdullah, N., Hanita, H., Ho, Y.W., Kudo, H., Julaludin, S. & Ivan, M., 1995. The effects of bentonite on rumen protozoal population and rumen fluid characteristics of sheep fed palm kernel cake. Asian-Aust. J. Anim. Sci. 8: 249-254.

Abrahamse, P.A., Dijkstra, J., Vlaeminck, B. & Tamminga, S., 2008. Frequent allocation of rotationally grazed dairy cows changes grazing behaviour and improves productivity. J. Dairy Sci. 91: 2033-2045.

Alimon, A.R., 2004. The nutritive value of palm kernel cake for animal feed. Palm Oil Developments 40. Malaysian Palm Oil Board. pp. 12-14.

Allen, M.S., 1997. Relationship between fermentation acid production in the rumen and the requirement for physically effective fibre. J. Dairy Sci. 80: 1447-1462.

Allen, M.S., 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83: 1598-1624.

AlZahal, O., Kebreab, E., France, J. & McBride, B.W., 2007. A mathematical approach to predicting biological values from ruminal pH measurements. J. Dairy Sci. 90: 3777-3785.

AOAC, 1984. Association of Official Analytical Chemists, Inc. Official Methods of Analysis of AOAC International, 14th ed., AOAC International, Arlington, Virginia, USA.

AOAC, 2000. Association of Official Analytical Chemists, Inc. Official Methods of Analysis of AOAC International, 17th ed., Vol 1. AOAC International, Maryland, USA.

ARC, 1984. The Nutrient Requirements of Ruminant Livestock. Agriculture Research Council. The Lavenham Press, Ltd., Lavenham, Suffolk, UK. pp. 59-60.

ARC. 2011. Agro-Climatology database. The Agricultural Research Council's Institute for Soil Climate and Water, Dept. of Agro-Climatology. I.O. van Gent, vgenti@arc.agric.za, Stellenbosch.

Bach, A., Yoon, I.K., Stern, M.D., Jung, H.G. & Chester-Jones, H., 1999. Effects of type of carbohydrate supplementation to lush pasture on microbial fermentation in continuous culture. J. Dairy Sci. 82: 153-160.

Baker, L.D., Ferguson, J.D. & Chalupa, W., 1995. Response in urea and true protein of milk to different protein feeding schemes for dairy cows. J. Dairy Sci. 78: 2424-2434.

Bargo, F., Muller, L.D., Delahoy, J.E. & Cassidy, T.W., 2002a. Milk response to concentrate supplementation of high producing dairy cows grazing at two pasture allowances. J. Dairy Sci. 85(7): 1777-1792.

Bargo, F., Muller, L.D., Kolver, E.S. & Delahoy, J.E., 2003. Invited review: Production and digestion of supplemented dairy cows on pasture. J. Dairy Sci. 86(1): 1-42.

Bargo, F., Muller, L.D., Varga, G.A., Delahoy, J.E. & Cassidy, T.W., 2002b. Ruminal digestion and fermentation of high producing dairy cows with three different feeding systems combining pasture and total mixed rations. J. Dairy Sci. 85(7): 2964–2973.

Beauchemin, K.A. & Rode, L.M., 1999. Effects of grain source and enzyme additive on site and extent of nutrient digestion in dairy cows. J. Dairy Sci. 82, 378-390.

Beauchemin, K.A., 1991. Ingestion and mastication of feed by dairy cattle. Vet. Clin. North Am. Food Anim. Pract. 7(2): 439-463.

Botha, P.R., 2002. Die gebruik van vogspanningmeters vir besproeiingskedulering by weidings. Weidingskursus Inligtingsbundel, 2002. Suid-Kaap Landbou-ontwikkelingsentrum, Departement Landbou, Wes-Kaap. pp 141-149.

Botha, P.R., 2003. Die Produksiepotensiaal van Oorgesaaide Kikoejoeweiding in die Gematigde Kusgebied van die Suid-Kaap. Doctoral dissertation. University of the Free-State, Bloemfontein, South Africa.

Botha, P.R., Meeske, R. & Snyman, H.A., 2008a. Kikuyu over-sown with ryegrass and clover-(i): Dry matter production, botanical composition and nutritional value. Afr. J. Range Forage Sci. 25(3): 93-101.

Botha, P.R., Meeske, R. & Snyman, H.A., 2008b. Kikuyu over-sown with ryegrass and clover-(ii): Grazing capacity, milk production and milk composition. Afr. J. Range Forage Sci. 25(3): 103-110.

Bradford, B.J. & Mullins, C.R., 2012. Invited review: Strategies for promoting productivity and health of dairy cattle by feeding nonforage fiber sources. J. Dairy Sci. 95: 4735-4746.

Broderick, G.A. & Kang, J.H., 1980. Automated simultaneous determination of ammonia and total amino acids in ruminal fluid and *in vitro* media. J. Dairy Sci. 63: 64-75.

Cajarville, C., Aguerre, M. & Repetto, J.L., 2006. Rumen pH, NH_3-N concentration and forage degradation kinetics of cows grazing temperate pastures and supplemented with different sources of grain. Anim. Res. 55 (6): 511-520.

Carrión, S., De Blas, J.C., Méndez, J., Caídas, A. & García-Rebollar, P., 2011. Nutritive value of palm kernel meal in diets for growing rabbits. Anim. Feed Sci. Technol. 165: 79-84.

Carruthers, V.R. & Neil, P.G., 1997. Milk production and ruminal metabolites from cows offered two pasture diets supplemented with non-structural carbohydrate. N.Z. J. Agric. Res. 40: 513-521.

Carruthers, V.R., Neil, P.G. & Dalley, D.E., 1997. Effects of altering the non-structural:structural carbohydrate ratio in a pasture diet on milk production and ruminal metabolites in cows in early and late lactation. Anim. Sci. 64: 393-402.

Carvalho, L.P.F., Cabritta, A.R.J., Dewhurst, R.J., Vicente, T.E.J., Lopes, Z.M.C. & Fonseca, A.J.M., 2006. Evaluation of palm kernel meal and corn distillers grains in corn silage-based diets for lactating dairy cows. J. Dairy Sci. 89: 2705-2715.

Chanjula, P., Mesang, A. & Pongprayoon, S., 2010. Effects of dietery inclusion of palm kernel cake on nutrient utilization, rumen fermentation characteristics and microbial populations of goats fed *Paspalum plicatulum* hay-based diet. Songklanakarin J. Sci. Technol. 32(6): 527-536.

Chanjula, P., Siriwathananukul, Y. & Lawpetchara, A., 2011. Effect of feeding rubber seed kernel and palm kernel cake in combination on nutrient utilization, rumen fermentation characteristics, and microbial populations in goats fed on *Briachiaria humidicola* hay-based diets. Asian-Aust. J. Anim. Sci. 24: 73-81.

Chin, F.Y., 2001. Palm kernel cake (PKC) as a supplement for fattening and dairy cattle in Malaysia. In: Forage Development in Southeast Asia: Strategies and Impacts. 7th Meeting of FAO Regional Working Group on grazing.

Clark, D.A. & Kanneganti, V.R., 1998. Grazing management systems for grazing cattle. Grass for dairy cattle. CAB International, Oxon, UK. pp. 331.

Coetzee, C., 2011. Supplementing live yeast to lactating Jersey cows grazing ryegrass/kikuyu pastures. Master's thesis. Dept. Anim. Wildlife Sci., University of Pretoria, Pretoria, South Africa.

Coetzee, K., 2012. Lacto Data Vol. 15 No. 1, May 2012 for Milk SA. Milk Producer's Organisation, koos.coetzee@mpo.co.za.

Collingwood, J.G., 1958. Palm kernel meal. Processed Plant Protein Foodstuffs. Academic Press Inc., New York. pp. 677-701.

Colman, E., Fokkink, W.B., Craninx, M., Newbold, J.R., De Baets, B. & Fievez, V., 2010. Effect of induction of subacute ruminal acidosis on milk fat profile and rumen parameters. J. Dairy Sci. 93: 4759-4773.

Crowther, C. & Woodman, H.E., 1917. The comparative digestibility of palm kernel cake, extracted palm kernel meal and undecorticated cottonseed cake. J. Agric. Sci. VIII: 429-447.

Cruywagen, C.W., 2006. Technical note: A method to facilitate the retrieval of polyester bags used in *in sacco* trials in ruminants. J. Dairy Sci. 89: 1028-1030.

Dalley, D.E., Roche, J.R., Grainger, C. & Moate, P.J., 1999. Dry matter intake, nutrient selection and milk production of dairy cows grazing rainfed perennial pastures at different herbage allowances in spring. Aust. J. Exp. Agric. 39: 923-931.

De Villiers, P., Petzer, I.M. & Erasmus, L., 2000. Chapter 8: The use of milk recording information as a herd management tool. In: Dairy Herd Improvement in South Africa. ARC- Animal Improvement Institute, Irene, RSA.

Delahoy, J.E., Muller, L.D., Bargo, F., Cassidy, T.W. & Holden, L.A., 2003. Supplemental carbohydrate sources for lactating dairy cows on pasture. J. Dairy Sci. 86: 906-915.

DePeters, E. J. & Ferguson, J. D., 1992. Nonprotein nitrogen and protein distribution in the milk of cows. J. Dairy Sci. 75: 3192-3209.

DePeters, E. J., & Cant, J. P., 1992. Nutritional factors influencing the nitrogen composition of bovine milk: a review. J. Dairy Sci. 75(8): 2043-2070.

Dickinson, E.B., Hyam, G.F.S., Breytenbach, W.A.S., Metcalf, H.D., Basson, W.D., Williams F.R., Scheepers, L.J., Plint, A.P., Smith, H.R.H., Smith, P.J., van Vuuren, P.J., Viljoen, J.H., Archibald, K.P. & Els, J.H., 2004. Kynoch pasture handbook (1st ed.). Paarl print, Cape Town, South Africa.

Dixon, R.M. & Stockdale, C.R., 1999. Associative effects between forages and grains: Consequences for feed utilization. Aust. J. Agric. Res. 50, 757–773.

Dowman, M.G., 1993. Modifications to the neutral detergent cellulase digestibility method for the prediction of the metabolisable energy of compound feedstuffs containing palm kernel meal. J. Sci. Food Agric. 61: 327-332.

Earle, D.F. & McGowan, A.A., 1979. Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. Aus. J. Exp. Agric. Anim. Husbandry. 19: 337-343.

Erasmus, L., 2009. Milk production from cows grazing kikuyu-ryegrass pasture systems. Master's thesis. Dept. Anim. Wildlife Sci., University of Pretoria, Pretoria, South Africa.

Erdman, R.A., 1988. Dietary buffering requirements of the lactating dairy cow: A review. J. Dairy Sci. 71: 3246-3266.

Erdman, R.A., Proctor, G.H. & Vandersall, J.H., 1986. Effect of rumen ammonia concentration on *in situ* rate and extent of digestion of feedstuff. J. Dairy Sci. 69: 2312-2320.

Everington, J.M., 1989. Recent developments in the evaluation of straights. In: B.A. Stark, J.M. Wilkinson & D.I. Givens (Eds.), Ruminant Feed Evaluation and Utilisation (pp. 13-24). Chalcombe Publications, Marlow.

Fales, S.L., Muller, L.D., Ford, S.A., O'Sullivan, M., Hoover, R.J., Holden, L.A., Lanyon, L.E. & Buckmaster, D.R., 1995. Stocking rate affects production and profitability in a rotationally grazed pasture system. J. Prod. Agric. 8: 88-96.

Fulkerson, W.J. & Slack, K., 1994. Management of *Lolium perenne*/*Trifolium repens* pasture in the sub-tropics 2. Effect of summer defoliation, irrigation duration, seedbed preparation and pasture type. Aust. J. Agric. Res. 45: 721-728.

Fulkerson, W.J., Nandra, K.S., Clark, C.F. & Barchia, I., 2006. Effect of cereal-based concentrates on productivity of Holstein-Friesian cows grazing short-rotation ryegrass (*Lolium multiflorum*) or kikuyu (*Pennisetum clandestinum*) pastures. J. Livestock Sci. 103: 85-94.

Fulkerson, W.J., Neal, J.S., Clark., C.F., Horadagoda, A., Nandra, K.S. & Barchia, J., 2007. Nutritive value of forage species grown in the warm temperate climate of Australia for dairy cows: Grasses and legumes. Livestock Sci. 107: 253-264.

Fulkerson, W.J., Slack, K., Hennessy, D.W. & Hough, G.M., 1998. Nutrients in ryegrass (*Lolium* spp.), white clover (*Trifolium repens*) and kikuyu (*Pennisetum clandestinum*) pastures in relation to season and stage of regrowth in a subtropical environment. Aust. J. Exp. Agric. 38: 227-240.

Gaines, W.L., 1928. The energy basis of measuring milk yield in dairy cows. University of Illinois, Agric. Exp. Station, Bulletin 308.

Gehman, A.M., Bertrand, J.A., Jenkins, T.C. & Pinkerton, B.W., 2006. The effect of carbohydrate source on nitrogen capture in dairy cows on pasture. J. Dairy Sci. 89: 2659-2667.

Gibb, M.J., Ivings, W.E., Dhanoa, M.S. & Sutton, J.D., 1992. Changes in body components of autumn-calving Holstein-Friesian cows over the first 29 weeks of lactation. Anim. Prod. 55(3): 339-360.

Gibson, J.P., 1989. Altering milk composition through genetic selection. J. Dairy Sci. 72: 2815-2825.

Giron, H.C., 1973. Perkin Elmer Atomic Spectrophotometer. Atomic Absorption Newsletter 12, 28.

Goering, H.K. & Van Soest, P.J., 1970. Forage Fiber Analysis: Apparatus, reagents, procedures and some applications. U.S.D.A.-A.R.S. Agric. Handbook no. 379. Government Printing Office, Washington, D.C., USA.

Gorosito, A.R., Russell, J.B & Van Soest, P.J., 1985. Effect of carbon-4 and carbon-5 volatile fatty acids on digestion of plant cell wall *in vitro*. J. Dairy Sci. 68: 840.

Hindle, V.A., Steg, A., Van Vuuren, A.M. & Vroons-de Bruin, J., 1995. Rumen degradation and post-ruminal digestion of palm kernel by-products in dairy cows. Anim. Feed Sci. Technol. 51: 103-121.

Hoover, W.H., 1986. Chemical factors involved in ruminal fibre digestion. J. Dairy Sci. 69(10): 2755-2766.

Hutagalung, R.I. & Mahyuddin, M.D., 1985. Nutritive value and feeding system on palm kernel cake and palm press fibre for ruminants. In: AAAP Proc. on Animal Production, 6-10 May 1985, Seoul, Korea, Vol. 2, pp. 983-985.

Ishler, V., Heinrichs, J. & Varga, G.A., 1996. From feed to milk: understanding rumen function. Extension circular 422. Pennsylvania State University, University Park, PA, pp. 1-27.

Jalaludin, S., Jelan, Z.A., Abdullah, N. & Ho, Y.W., 1991. Recent developments in the oil palm by-product based ruminant feeding system. Proc. 3rd International Symposium: Recent Advances on the Nutrition of Herbivores. Malaysian Society of Animal Production Serdang, Malaysia. pp. 35-44.

Jenkins, T.C. & McGuire, M.A., 2006. Major advances in nutrition: Impact on milk composition. J. Dairy Sci. 89: 1302-1310.

Jonker, J.S., Kohn, R.A. & Erdman, R.A., 1999. Milk urea nitrogen target concentrations for lactating dairy cows fed according to National Research Council recommendations. J. Dairy Sci. 82: 1261-1273.

Kaiser, R., and R. Shaver. 2006. Benchmarking high producing herds. Proc. Western Canadian Dairy Seminar. Red Deer, Alberta, Canada. 18:179-190.

Kalscheur, K.F., Teter, B.B., Piperova, L.S. & Erdman, R.A., 1997. Effect of dietary forage concentration and buffer addition on duodenal flow of *trans*-$C_{18:1}$ fatty acids and milk fat production in dairy cows. J. Dairy Sci. 80: 2104-2114.

Kellaway, R.C. & Porta, S., 1993. Feeding concentrates supplements for dairy cows. Dairy Research and Development Corporation, Melbourne, Australia.

Kellaway, R.C., Tassel, R.J., Havilah, E., Sriskandarajah, N. & Andrews, A., 1993. Nutrient balance in the diet of grazing dairy cows. Aust. J. Agric. 44 (3): 423-430.

Kennelly, J.J. & Glimm, D.R., 1998. The biological potential to alter the composition of milk. Canadian J. Anim. Sci. 78: 23-56.

Khalili, H. & Sairanen, A., 2000. Effect of concentrate type on rumen fermentation and milk productions of cows at pasture. Anim. Feed Sci. Tech. 84: 199-212.

Kitchen, J.B., 1981. Review of the progress of dairy science: Bovine mastitis: Milk compositional changes and related diagnostic tests. J. Dairy Res. 48: 167-188.

Kohn, R., 2007. Use of milk or blood urea nitrogen to identify feed management inefficiencies and estimate nitrogen excretion by dairy cattle and other animals. Florida Ruminant Nutrition Symposium, Gainesville, Florida, USA.

Kolver, E.S. & Muller, L.D., 1998. Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. J. Dairy Sci. 81: 1403-1411.

Kolver, E.S., Muller, L.D., Barry, M.C. & Penno, J.W., 1998a. Evaluation and application of the Cornell Net Carbohydrate and Protein System for dairy cows fed diets based on pasture. J. Dairy Sci. 77: 813-824.

Kolver, E.S., Muller, L.D., Varga, G.A. & Cassidy, T.J., 1998b. Synchronization of ruminal degradation of supplemental carbohydrate with pasture nitrogen in lactating dairy cows. J. Dairy Sci. 81: 2017-2028.

Lehmann, M., Meeske, R. & Cruywagen, C.W., 2007. Milk production and *in sacco* disappearance of of pasture NDF and grazing cows receiving a barley based concentrate. S. Afr. J. Anim. Sci. 37: 81-82.

Lingnau, W.A.L., 2011. Substitution of maize with high fibre by-products in concentrates supplemented to dairy cows grazing kikuyu/ryegrass pasture during spring. Master's thesis. University of Stellenbosch, Stellenbosch, South Africa.

Lowe, K.F., Bowdler, T.M., Casey, N.D. & Moss, R.J., 1999. Performance of temperate perennial pastures in the Australian subtropics 1. Yield persistence and pasture quality. Aust. J. Exp. Agric. 39: 663-676.

Malleson, E.R., 2008. Fishmeal supplementation to high producing Jersey cows grazing ryegrass or kikuyu pasture. Master's thesis. Dept. Anim. Wildlife Sci., University of Pretoria, Pretoria, South Africa.

Marais, J.P., 2001. Factors affecting the nutritive value of kikuyu grass (*Pennisetum clandestinum*) — a review. Trop. Grassl.. 35: 65-84.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D. & Morgan, C.A., 2002. Animal Nutrition. Sixth Edition. Pearson Education Limited, Edinburg, Gate, Harlow, Essex.

McGilloway, D.A. & Mayne, C.S., 1996. The importance of grass availability for the high genetic merit dairy cow. In: P.C. Garnsworthy, J. Wiseman & W. Haresign (Eds.), Recent Advances in Animal Nutrition. Nottingham University Press, UK.

Meeske, R., Cronje, P.C. & Van der Merwe, G.D., 2009. High fibre concentrates for Jersey cows grazing kikuyu/ryegrass pasture. Proc. Annual Information Day at Outeniqua Research Farm. 6 October 2009. pp. 40-42.

Meeske, R., Rothauge, A., Van der Merwe, G.D. & Greyling, J.F., 2006. The effect of concentrate supplementation on the productivity of grazing Jersey cows on a pasture based system. S. Afr. J. Anim. Sci. 36 (2): 105-110.

Meijs, J.A.C., 1986. Concentrate supplementation of grazing dairy cows. 2. Effect of concentrate composition on herbage intake and milk production. Grass Forage Sci. 41: 229-235.

Mertens, D.R., 1979. Effects of buffers on fibre digestion. In: W.H. Hale & P. Meinhardt (Eds.), Regulation of acid-base balance (pp. 65). Church and Dwight Co. Inc., Pistaway, NJ.

Microsoft Office, 2010. Microsoft Excel. Microsoft. Redmond, Washington, USA.

Ministry of Agriculture, Fisheries and Food, 1984. Energy allowances and feeding systems for ruminants. London, HMSO.

Ministry of Agriculture, Fisheries and Food, 1992. In: Feed Composition. UK Tables of Feed Composition and Nutritive Value for Ruminants, 2nd ed., Chalcombe Publications, Nr. Canterbury, UK.

Minson, D.J., 1991. Intake of grazed forage. In: Forage in ruminant nutrition. Academic Press Inc., Sydney, Australia. pp. 60-84.

Moss, A.R. & Givens, D.I., 1994. The chemical composition, digestibility, metabolisable energy content and nitrogen degradability of some protein concentrates. Anim. Feed Sci. Technol. 47: 335-351.

Mould, F.L., Ørskov, E.R. & Mann, S.O., 1984. Associative effects of mixed feeds: Effects of type and level of supplement and the influence of the rumen fluid pH on cellulolysis *in vivo* and dry matter digestion of various roughages. Anim. Feed Sci. Tech. 10: 15-30.

Muller, L.D. & Fales, S.L., 1998. Supplementation of cool-season grass pastures for dairy cattle. In: J.H. Cherney & D.J.R. Cherney (Eds.), Grass for dairy cows (pp. 335-350). CABI Publishing, New York, NY.

Muller, L.D., Delahoy, J. & Bargo, F., 2001. Supplementation of lactating cows on pasture. Pennsylvania State University. http://www.das.psu.edu/research-extension/dairy/nutrition/pdf/supplementation-of-lactating-cows.pdf.

National Research Council, 1989. Nutrient Requirements of Dairy Cattle, Sixth Rev. Ed. National Academic of Sciences, Washington, D.C., USA.

National Research Council, 2001. Nutrient Requirements of Dairy Cattle, Seventh Rev. Ed. National Academic Press, Washington, D.C., USA.

Nocek, J. E. 1997. Bovine acidosis: Implications on laminitis. J. Dairy Sci. 80: 1005-1028.

Nordlund, K. V., and E. F. Garrett. 1994. Rumenocentesis: A technique for the diagnosis of subacute rumen acidosis in dairy herds. Bovine Pract. 28: 109-112.

O'Mara, F.P., Mulligan, F.J., Cronin, E.J., Rath, M. & Caffrey, P.J., 1999. The nutritive value of palm kernel meal measured in vivo and using rumen fluid and enzymatic techniques. Livestock Prod. Sci. 60: 305-316.

Ørskov, E.R. & Istasse, L., 1983. The correlation between extent of pH depression and degradability of washed hay in sheep given hay and concentrate. Proc. Nutr. Soc. 42: 32A.

Owens, F., Secrist, D., Hill, J. & Gill, D., 1996. A new look at acidosis. Proc. Southwest Nutrition Conf., Hoenix, AZ. pp. 1-16.

Peyraud, J.L. & Delaby, L., 2001. Ideal concentrate feeds for grazing dairy cows responses to supplementation in interaction with grazing management and grass quality. In: P.C. Garnsworthy & J. Wisemman (Eds.), Recent Advances in Animal Nutrition (pp. 203). Notthingham University Press, UK.

Pitt, R.E., Van Kessel, J.S., Fox, D.J., Pell, A.N., Barry, M.C. & Van Soest, P.J., 1996. Predictions of rumen volatile fatty acids and pH within the net carbohydrate and protein system. J. Anim. Sci. 74: 226-244.

Ranathunga, S.D., Kalscheur, K.F., Hippen, A.R. & Schingoethe, D.J., 2010. Replacement of starch from corn with nonforage fibre from distillers grains and soyhulls in diets of lactating dairy cows. J. Dairy Sci. 93: 1086-1097.

Reeves, M., 1997. Milk production from kikuyu (*Pennisetum clandestinum*) grass pasture. Doctoral dissertation. University of Sydney, Sydney, Australia.

Reeves, M., Fulkerson, W.J. & Kellaway, R.C., 1996a. Forage quality of kikuyu (*Pennisetum clandestinum*): the effect of time of defoliation and nitrogen fertiliser application and in comparison to perennial ryegrass. Aust. J. Agric. Res. 47: 1349-1359.

Reeves, M., Fulkerson, W.J., Kellaway, R.C. & Dove, H., 1996b. A comparison of three techniques to determine the herbage intake of dairy cows grazing kikuyu (*Pennisetum clandestinum*) pasture. Aus. J. Exp. Agric. Anim. Husbandry. 36: 23-30.

Reis, R.B. & Combs, D.K., 2000. Effects of increasing levels of grain supplementation on rumen environment and lactation performance of dairy cows grazing grass-legume pasture. J. Dairy Sci. 83: 2888-2898.

Robertson, J.B. & Van Soest, P.J., 1981. The Analysis of Dietary Fibre in Food. Dekker, New York. ADSRI-JAN 1988.

Robinson, P.H., 1983. Development and initial testing of an in vivo system to estimate rumen and whole tract digestion in lactating dairy cows. Doctoral dissertation. Cornell University, Ithaca, New York.

Roche, J.R., Dillon, P.G., Stockdale, C.R., Baumgard, L.H., & VanBaale, M.J., 2004. Relationship among international body condition scoring systems. J. Dairy Sci. 87: 3076-3079.

Rodriguez, L.A., Stallings, C.C., Herbein, J.H. & McGilliard, M.L., 1997. Effect of degradability of dietary protein and fat on ruminal, blood, and milk components of Jersey and Holstein cows. J. Dairy Sci. 80: 353-363.

Roseler, D.K., Ferguson, J.D., Sniffen, C.J. & Herrema, J., 1993. Dietary protein degradability effects on plasma and milk urea nitrogen and milk nonprotein nitrogen in Holstein cows. J. Dairy Sci. 76: 525-534.

Sairanen, A., Khalili, H. & Virkajarvi, P., 2006. Concentrate supplementation responses of the pasture-fed dairy cow. Livestock Sci. 104: 292-302.

Samuels, M.L., 1989. Statistics for the life sciences. Collier MacMillan Publishers, London.

Sanderson, M.A., Rotz, C.A., Fultz, S.W. & Rayburn, E.B., 2001. Estimating forage mass with a commercial capacitance meter, rising plate meter, and pasture ruler. Agron. J. 93: 1281-1286.

Satter, L.D. & Slyter, L.L., 1974. Effect of ammonia concentration on rumen microbial protein production *in vitro*. Br. J. Nutr. 32: 199-208.

Sayers, H.J., 1999. The effect of sward characteristics and level and type of supplement on grazing behaviour, herbage intake and performance of lactating dairy cows. Doctoral dissertation. Queen's University of Belfast. The Agricultural Research Institute of Northern Ireland. Hillsborough.

Sayers, H.J., Mayne, C.S. & Bartram, C.G., 2003. The effect of level and type of supplement offered to grazing dairy cows on herbage intake, animal performance and rumen fermentation characteristics. Anim. Sci. 76(3): 439-454.

Seymour, W.M., Campbell, D.R. & Johnson, Z.B., 2005. Relationship between rumen volatile fatty acid concentrations and milk production in dairy cows: a literature review. Anim. Feed Sci. Tech. 119: 155-169.

Shaver, R.D., 2008. Coping with high corn prices: low starch diets and lactation performance by dairy cows. Proc. 6th Mid-Atlantic Nutr. Conf. Timonium, MD.

Smith, H.J., Taweel, H.Z., Tas, B.M., Tamminga, S. & Elgarsma, A., 2005a. Comparison of techniques for estimating herbage intake of grazing dairy cows. J. Dairy Sci. 88: 1827-1836.

Smith, K.F., Tas, B.M., Taweel, H.Z., Tamminga, S. & Elgersma, A., 2005b. Effects of perennial ryegrass (*Lolium perenne* L.) cultivars on herbage production, nutritional quality and herbage intake on grazing dairy cows. Grass Forage Sci. 60: 297-309.

Soil Classification Working Group, 1991. Soil classification. A taxonomic system for South Africa. Memoirs of natural agricultural resources of South Africa, No 15. Dept. of Agric. Dev., Pretoria.

Staples, C.R. 2007. Feeding dairy cows when corn prices are high. Proc. 44th Florida Dairy Production Conference. Gainesville, FL.

Statistical Analysis Systems Institute, 2012. SAS User`s Guide: Statistics Version 9.2. SAS Institute Inc., Cary, North Carolina, USA.

Steyn, L., 2012. Supplementation of a high fibre concentrate to Jersey cows on pasture to overcome winter roughage shortages. Master's thesis. University of Stellenbosch, Stellenbosch, South Africa.

Stockdale, C. R., 1984. Evaluation of techniques for estimating the yield of irrigated pastures intensively grazed by dairy cows. 2: The rising plate meter. Aus. J. Exp. Agric. Anim. Husbandry. 24: 305-311.

Stockdale, C. R., 2000. Levels of pasture substitution when concentrates are fed to grazing dairy cows in Northern Victoria. Aust. J. Exp. Agric. 40(7): 913-922.

Stockdale, C.R., Walker, G.P., Wales, W.J., Dalley, D.E., Birkett, A., Shen, Z. & Doyle, P.T., 2003. Influence of pasture and concentrates in the diet of grazing dairy cows on the fatty acid composition of milk. J. Dairy Res. 70: 267-276.

Sutton, J.D., 1984. Feeding and milk fat production. In: M.E. Castle & R.G. Gunn (Eds.), Milk compositional quality and its importance in future markets (pp. 43-52). Brit. Soc. Anim. Prod. occasional publication.

Sutton, J.D., 1989. Altering milk composition by feeding. J. Dairy Sci. 72: 2801-2814.

Sutton, J.D., Hart, I.C., Broster, W.H., Elliott, R.J. & Schuller, E., 1986. Feeding frequency for lactating cows: effects on rumen fermentation and blood metabolites and hormones. Brit. J. Nutr. 56: 181-192.

Tas, B.M., Taweel, H.Z., Smith, H.J., Elgersma, A., Dijkstra, J. & Tamminga, S., 2005. Effects of perennial ryegrass cultivars on intake, digestibility, and milk yield in dairy cows. J. Dairy Sci. 88: 3240-3248.

Taweel, H.Z., Tas, B.M., Williams, B.A., Dijkstra, J., & Tamminga, S., 2004. Fibre degradation rate of perennial ryegrass varieties measured using three techniques: in situ nylon bag, *in vivo* rumen evacuation and in vitro gas production. Doctoral dissertation. Wageningen University, Wageningen, Netherlands. Chapter 3.

Thom, E.R. & Prestidge, R.A., 1996. Use of Italian ryegrass on seasonal dairy farms in northern New Zealand 1. Feed production and persistence. New Zealand J. Agric. Res. 39: 223-236.

Thomas, P.C. & Chamberlain, D.G., 1984. Manipulation of milk composition to meet market needs. In: W. Haresign & D.J.A. Cole (Eds.), Recent Advances in Animal Nutrition (pp. 219-243). Butterworths, London.

Tilley, J.M. & Terry, R.A., 1963. A two-stage technique for the *in vitro* digestion of forage crops. J. Br. Grassl. Soc. 18: 104-111.

Trevaskis, L.M. & Fulkerson, W.J., 1999. The relationship between various animal and management factors and milk urea, and its association with reproductive performance of dairy cows grazing pasture. Livestock Prod. Sci. 57: 255-265.

Van Amburgh, M. E., Van Soest, P.J., Robertson, J.B. & Knaus, W.F., 2003. Corn silage neutral detergent fiber: Refining a mathematical approach for *in vitro* rates of digestion. Dept. Anim. Sci., Cornell University, Ithaca, New York, USA. http://www.foragelab.com/pdf/FeedReports/VanAmburgh_CornSilageNDFDigestionRate.pdf.

Van der Colf, J., 2011. The production potential of Kikuyu (*Pennisetum clandestium*) pastures over-sown with Ryegrass (*Lolium spp.*). Master's thesis. University of Pretoria, Pretoria, South Africa.

Van Soest, P.J., 1982. Nutritional ecology of the ruminant. O & B Books Inc., Corvallis, Oregon, USA, pp. 252.

Van Straalen, W.M., Odinga, J.J. & Mostert, W., 1997. Digestion of feed amino acids in the rumen and small intestine of dairy cows measured with nylon-bag techniques. Br. J. Nutr. 77: 83-97.

Van Vuuren, A.M., Tamminga, S. & Ketelaar, R.S., 1991. *In sacco* degradation of organic matter and crude protein of fresh grass (*Lolium perenne*) in the rumen of grazing dairy cows. J. Agric. Sci. 116: 429-439.

Van Vuuren, A.M., Van der Koelen, J. & Vroons-de Bruin, J., 1986. Influence of the level and composition of concentrate supplements on rumen fermentation patterns of grazing dairy cows. Neth. J. Agric. Sci. 34: 457-467.

Vanzant, E.S., Cochran, R.C. & Titgemeyer, E.C., 1998. Standardization of *in situ* techniques for ruminant feedstuff evaluation. J. Anim. Sci. 76: 2717-2729.

Varga, G.A., Dann, H.M. & Ishler V.A., 1998. The use of fibre concentrations for ration formulation. J. Dairy Sci. 81: 3063-3074.

Webb, E.C., 1994. Synthesis of long chain fatty acids in ruminants and their effects on meat quality. Doctoral dissertation. University of Pretoria, Pretoria, South Africa. Chapter 3, pp. 58-59.

Welper, R.D. & Freeman, A.E., 1992. Genetic parameters for yield traits of Holsteins, including lactose and somatic cell score. J. Dairy Res. 75(5): 1342-1348.

Wildman, E.E., Jones, G.M., Wagner, P.E., Boman, R.L., Troutt, H.F. & Jr., Lesch, T.N., 1982. A dairy cow body condition scoring system and its relationship to selected production characteristics. J. Dairy Sci. 65: 495-501.

Wong, H.K. & Zahari, M.W., 1997. Nutritive value of palm kernel cake and cocoa pod husks for growing cattle. J. Trop. Agric. Food Sci. 25(1): 25-131.

Yang, W.Z., Beauchemin, K.A. & Rode, L.M., 2001. Effects of grain processing, forage to concentrate ratio, and forage particle size on rumen pH and digestion by dairy cows. J. Dairy Sci. 84: 2203–2216.

Yeong, S.W., Mukherjee, T.K. & Hutagulung, R.I., 1983. The nutritive value of palm kernel cake as a feedstuff for poultry. Proc. of the National Workshop on Oil Palm By-products Utilization. pp. 100-107.

Zahari, M.W. & Alimon, A.R., 2003. Use of palm kernel cake and oil palm by-products in compound feed. Palm oil developments 40. Malaysian Palm Oil Board. pp 5-9.

Zebeli, Q., Dijkstra, J., Tafaj, M., Steingass, H., Ametaj, B.N. & Drochner, W., 2008a. Modelling the adequacy of dietary fiber in dairy cows based on the response of ruminal pH and milk fat production to composition of the diet. J. Dairy Sci. 91: 2046-2066.

Zebeli, Q., Tafaj, M., Weber, I., Steingass, H. & Drochner, W., 2008b. Effects of dietary forage particle size and concentrate level on fermentation profile, *in vitro* degradation characteristics and concentration of liquid- or solid-associated bacterial mass in the rumen of dairy cows. Anim. Feed Sci. Technol. 140: 307-325.

APPENDIX A

Table A1 The blocking sequence of the individual cows according to 4% fat corrected milk, days in milk and lactation number with their randomly allocated treatments

Cow name	Lactation no.	DIM[1] 17/08/2011	4% FCM[2]	Block	Treatment[3]
TPANS 6	3	69	33.1	1	3
TSUSA 17	7	84	32.9	1	1
TAMSA 48	4	78	31.7	1	2
TARNA 3	7	91	30.7	2	1
TLUA 22	4	80	30.5	2	3
TMAX 13	8	46	30.1	2	2
TMAX 26	4	96	29.9	3	3
TPANS 11	2	47	29.8	3	2
TLUA 20	4	47	29.7	4	3
TSUSA 54	3	80	29.3	4	1
TAMSA 64	3	109	29.1	3	1
TWANDA 15	3	51	28.8	5	1
TAMSA 90	2	47	28.8	4	2
TSANTA 5	6	131	28.7	5	2
TMELBA 1	5	98	28.6	6	3
TBERTA 61	5	77	28.6	6	1
TBERT 29	6	80	28.5	7	1
TSUSA 43	4	100	28.2	5	3
TTES 15	2	85	28.2	6	2
TPAUL 12	3	107	27.6	7	3
TAMSA 65	3	117	27.6	7	2
TPANS 10	2	31	27.2	9	1
TAMSA 58	3	163	27.0	9	3
TPAUL 13	4	85	26.9	8	2
TBERT 34	5	127	26.7	8	3
TMONA 13	2	128	26.7	8	1
TMAX 18	5	159	26.6	9	2
TPAUL 18	2	51	24.3	10	3
TBERTA 58	3	126	23.4	10	1
TAMSA 77	2	126	23.3	10	2
TSUSA 37	4	93	23.3	11	1
TAMSA 11	8	36	23.1	11	3
TWAND 11	4	21	23.1	11	2
TPAUL 11	4	24	22.9	12	3
TBERT 22	8	70	22.4	13	3
TETNA 9	2	67	22.1	12	1
TMAX 25	4	115	21.9	13	2
TPAUL 17	2	93	21.5	12	2
TBERT 36	7	92	21.2	13	1
TAMSA 13	7	153	21.1	14	1
TSUSA 59	2	159	21.0	14	3
TWANDA 23	2	23	20.6	14	2
TSUSA 48	3	136	20.5	15	1
TLUA 21	4	122	20.4	15	2
TLIZ 13	5	22	20.2	15	3
THES 7	2	21	19.8	16	2
TAMSA 68	3	19	19.3	16	1
TAMSA 88	2	28	18.7	16	3

[1]DIM – days in milk
[2]FCM – fat corrected milk (as from 25 Julie to 15 August 2011)
[3]Treatment 1 – Control; Treatment 2 – Low PKE; Treatment 3 – High PKE