Supplementing high fibre concentrates to Jersey cows grazing kikuyu pastures during summer

by

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Date: March 2016

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Date: March 2016

ABSTRACT

Title: Supplementing high fibre concentrates to Jersey cows grazing kikuyu pastures during summer

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Dairy cattle grazing kikuyu pastures are faced with several challenges in nutrient shortages to achieve high milk production. With energy being the first limiting nutrient in kikuyu pastures, supplementation is essential. Currently, high-starch concentrates are used as conventional dairy concentrates. These concentrates are, however, expensive and could affect rumen parameters negatively. Improving the efficiency of production and reducing the cost of supplements could be achieved by replacing energy and protein with cheaper by-products. High fibre by-products can be an economically viable option during periods of high maize and high protein prices. Hominy chop, wheat bran and gluten 20 were used in this study to reduce the price of the supplement. There are many different variables that influence the price of raw materials and these should be taken into account when looking at this study. The objective of the current study was to determine the effect of replacing maize with high fibre by-products in the supplement fed to dairy cows grazing kikuyu pasture on milk production responses and selected rumen parameters.

The study was conducted at the Outeniqua Research Farm situated near George in the Western Cape during the summer. A randomised block design was used to allocate 51 cows as follows to the respective treatments (low, medium and high fibre supplement) on the basis of milk yield (kg): 19.8 ± 2.2 (SD), 19.6 ± 1.9, 19.6 ± 1.9, days in milk (DIM): 95.5 ± 41.7, 91.5 ± 46.8, 87.7 ± 40.4, lactation number: 3.9 ± 1.7, 3.9 ± 1.1, 3.9 ± 1.6 and body weight (kg): 387 ± 30.1, 384 ± 23.0, 386 ± 28.7. The low, medium and high fibre treatments contained 78.5, 50.8 and 22.7% maize. Maize was partially replaced by high fibre by-products such as hominy chop, wheat bran and gluten 20. Additionally, six ruminally cannulated Jersey cows were randomly allocated to two treatments (low fibre and high fibre) in a cross-over design. Rumen parameters that were measured included rumen pH, volatile fatty acid (VFA) profile and rumen ammonia nitrogen (NH_3-N). Cows were fed 6 kg (split over two milkings per day) concentrate per day and were allocated fresh kikuyu pasture after each milking. Cows grazed the allocated pasture as one group.

There were no differences found in milk yield, milk fat, kg fat, fat corrected milk, milk urea nitrogen, and total solids amongst treatments. The milk protein, lactose and solids non-fat (SNF) were 36.6^{a}, 35.3^{ab}, 34.5^{b} g/kg; 47.3^{a}, 47.3^{a}, 44.9^{b} g/kg and; 90.4^{a}, 89.0^{ab}, 87.2^{b} g/kg for the low, medium and high fibre treatment, respectively. Somatic cell count was lower in the low fibre treatment ($P < 0.05$) 141^{a}, 145^{b}, 230^{b} x10^{3} cells/mL milk. The rumen pH and rumen NH_3-N did not differ between treatments. Total VFA and VFA proportions did not differ between treatments, however, the iso-valeric acid was higher in the high fibre treatment (1.49 *vs*. 1.23 mmol/dL $P < 0.05$). There were no signs of clinical acidosis which indicates that rumen health was maintained.

It was concluded that by partially substituting maize with high-fibre by-products, milk yield can be sustained. However milk protein, lactose and SNF composition may be lower. The partial substitution of maize with high fibre by-products in dairy concentrates can be used to overcome energy shortages as well as maintain rumen activity and health.

UITTREKSEL

Titel: Supplementering van hoë-vesel kragvoere aan Jerseykoeie op kikoejoeweiding gedurende die somer.

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Melkkoeie wat permanent op kikoejoeweiding aangehou word, staar vele uitdagings in die gesig ten opsigte van voedingstekorte ten einde höe melkproduksies te bereik. Aangesien energie die eerste beperkende voedingstof op kikoejoeweiding is, is aanvulling noodsaaklik. Hoëstyselkragvoere word konvensioneel vir melkkoeie gebruik, maar dit is duur en het die potensiaal om die rumenomgewing negatief te beïnvloed. Melkproduksievlakke en die koste van aanvullings kan verbeter deur die energie en proteïen te vervang met goedkoper produkte. Hoëveselprodukte kan 'n ekonomiese alternatief wees ten tye van hoë mielie- en proteïenpryse. "Hominy chop", koringsemels en mieliegluten 20 is in die huidige navorsing gebruik om die koste van die aanvulling te verlaag. 'n Verskeidenheid faktore kan grondstofpryse beïnvloed en dit moet in ag geneem word wanneer hierdie studie in oënskou geneem word. Die doel van die studie was om die invloed van hoëvesel neweprodukte as plaasvervanger vir mielies in aanvullings van weidende koeie op melkproduksie en bepaalde rumenparameters na te gaan.

Die navorsing is gedurende die somer op die Outeniqua Proefplaas naby George in die Wes-Kaap gedoen. 'n Ewekansige blokontwerp is gebruik om 51 koeie as volg aan die onderskeie behandelings (lae-, medium- en hoë-vesel aanvulling) toe te ken op grond van melkproduksie (kg): 19.8 ± 2.2 (SD), 19.6 ± 1.9, 19.6 ± 1.9, dae in melk (DIM): 95.5 ± 41.7, 91.5 ± 46.8, 87.7 ± 40.4, laktasienommer: 3.9 ± 1.7, 3.9 ± 1.1, 3.9 ± 1.6 en liggaamsmassa (kg): 387 ± 30.1, 384 ± 23.0, 386 ± 28. Die lae-, medium- en hoëveselbehandelings het onderskeidelik 78.5, 50.8 en 22.7% mielies bevat. Die mielies is gedeeltelik vervang met "hominy chop", koringsemels en mieliegluten 20. Verder is ses rumen-gekannuleerde Jerseykoeie ewekansig aan twee behandelings (lae- en hoëvesel) in 'n omswaai-ontwerp toegeken. Rumenparameters wat gemeet is, sluit in rumen pH, vlugtige vetsure (VVS) en rumen-ammoniakstikstof (NH_3-N).

Die koeie het elk daagliks 6 kg kragvoer ontvang (3 kg per melkings) en vars kikoejoeweiding was beskikbaar na elke melking. Die koeie het as een groep op die geallokeerde weiding gewei.

Geen verskille in melkoproduksie, bottervetinhoud, kg vet, vetgekorrigeerde melkproduksie, melkureumstikstof en melkvastestowwwe is tussen behandelings waargeneem nie. Die melkproteïen, laktose en vetvrye vastestofinhoud was 36.6^{a}, 35.3^{ab}, 34.5^{b} g/kg; 47.3^{a}, 47.3^{a}, 44.9^{b} g/kg and; 90.4^{a}, 89.0^{ab}, 87.2^{b} g/kg vir die lae-, medium- en hoëvesel behandelings. Somatise seltelling was laer in die laeveselbehandeling ($P < 0.05$) en waardes was onderskeidelik 141^{a}, 145^{b}, 230^{b} $x10^{3}$ selle/ml melk. Die rumen pH en rumen-NH_3-N het nie verskil tussen behandelings nie. Totale VVS en VVS proporsies het ook nie tussen behandelings verskil nie, maar die iso-valeriaansuurinhoud was hoër in die hoëvesel behandeling (1.49 *vs*. 1.23 mmol/dL $P < 0.05$). Daar was geen tekens van kliniese asidose nie, wat aandui dat rumengesondheid gehandhaaf is.

Die gevolgtrekking is gemaak dat melkproduksie gehandhaaf kan word deur die gedeeltelike vervanging van mielies met hoëvesel neweprodukte. Die melkproteïen-, laktose- en vetvrye vastestofinhoud mag egter laer wees. Die gedeeltelike vervanging van mielies met hoëvesel neweprodukte in kragvoeraanvullings vir melkkoei op weiding kan gebruik word om energietekorte te oorbrug en terselfdertyd rumenaktiwiteit en rumengesondheid te behou.

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Table of Contents

List of Tables

List of Figures

CHAPTER 1

Introduction

The international economic growth has declined from 2010 to 2014 and according to the International Monetary Fund (IMF) its projected growth figures for 2015 and 2016 were adjusted downwards by an average of 0.3 percentage points (Lactodata, 2015). International food prices are highly volatile, with dairy prices showing the highest volatility (Lactodata, 2015). With the volatile milk price and the increase in cost of production, the trend towards higher production in the pasture-based areas of South Africa has continued. This will necessitate the development of grazing systems designed to maximise daily herbage intake per cow, while at the same time maintain a high-quality pasture over the entire grazing season (Dillon, 2006).

The ever increasing demand for milk and milk products exerts pressure on dairy producers to increase productivity and efficiency. The success of pasture-based systems was traditionally based on high herbage utilization accompanied by high stocking rates which often compromised individual animal performance. Grazed forages are currently the cheapest nutrient source for dairy cows (McEvoy *et al*., 2009). It would seem that the future success of pasture-based systems will have to be based on achieving maximum daily herbage intake per animal from grazed pasture while maintaining a sufficient quantity of high quality pasture throughout the whole growing season (Dillon, 2006).

In the Southern Cape of South Africa, kikuyu (*Pennisetum clandestinum*) is the dominant cultivated grass species during the summer months. The first limiting nutrient of kikuyu is energy and to overcome this, supplementation is necessary to meet the demands of high producing cows. Dairy concentrates contribute up to 66% of the total feed cost in pasture grazing systems (Meeske *et al*., 2006). Starch, in the form of maize, can contribute up to 70 to 80% of a conventional dairy concentrate and oilcake up to 12% (Meeske *et al*., 2009). Both of these feed sources are costly and the price is volatile due to several factors, including; exchange rate, availability etc. Due to its high starch content, maize permits the formulation of energy-dense diets required by high-producing dairy cows and promotes microbial protein synthesis in the rumen. However, increasing dietary starch from maize grain at the expense of forage fibre has been demonstrated to negatively affect rumen function. Excess fermentation of starch to VFA in the rumen disturbs the buffering and absorptive capacity of cows, leading to decreased ruminal pH. Lower ruminal pH may decrease appetite, fibre digestion, microbial yield, and milk fat concentration (Mould *et al*., 1983; Kalscheur *et al.*, 1997).

The partial substitution of starch with cost-effective, low starch, non-forage energy sources represents a potential alternative to help overcome these issues. In a study previously conducted on ryegrass (*Lolium perenne*) 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 could also result in an increase in pasture intake and total dry matter intake (DMI) (Meijs, 1986; Sayers, 1999).

There are several benefits to supplementing dairy cows on kikuyu pastures with concentrates. These benefits include increased milk production per cow, increased stocking density and milk production per unit land, improvement in pasture utilisation, maintenance of the animal's body condition score at acceptable levels which can improve reproduction, increased lactation periods during times of pasture shortages and an increase in the dairy farm's profitability (Bargo *et al*., 2003).

Supplementation on a pasture-based system exposes the rumen to two different components in their diet (pasture and concentrates) which causes an inconsistent rumen environment. The slug feeding of highly fermentable carbohydrates separate from the main roughage source (pasture) results in extreme rumen environments that could lead to reduced pasture utilisation rates, decreased milk production and eventually health problems. Rumen pH is one of the most variable factors that can influence rumen microbial populations and volatile fatty acid production (Ishler *et al*., 1996). Fibre digesters, such as cellulolytic and methanogenic bacteria, are most effective at a pH of between 6.2 and 6.8, with effectiveness decreasing as the rumen pH decreases below 6.0 (Ishler *et al*., 1996). In order to accommodate the requirements of all the different rumen micro organisms, it is important that normal feeding practices maintain a rumen pH of between 5.8 and 6.4 (Ishler *et al*., 1996). Fibre based concentrates have been shown to depress milk production while increasing milk fat percentage (Bargo *et al*., 2003). The addition of non forage fibre to the concentrate of dairy cows may also improve the stability of rumen environment in dairy cows grazing pasture, leading to increased pasture intake.

The partial substitution of maize with high fibre by-products, fed to grazing dairy cows, could be a viable option. It could lead to the same milk production as indicated by Kibbon and Holmes

(1987), Spörndly (1991), Fisher *et al*. (1996) and Sayers *et al*. (2003). According to Meijs (1986), Khalili and Sairanen (2000) and Meeske *et al*. (2009), milk production increased when high fibre by-products were fed. The cost of the concentrate can be reduced if the by-products are cheaper than maize. If the milk production can be maintained, the gross margin can increase due to a lower concentrate cost. A high fibre concentrate has been shown to have a positive effect on milk fat percentage (Lingnau, 2011; Meijs, 1986; Meeske *et al*., 2009). Depending on the market for milk and the milk buyer, the price per litre could be structured around milk solids as opposed to volumes alone. Dairy farm profitability can be maximised by maintaining nutrient levels while managing feed costs as well as improving overall health (Ishler *et al*., 1996).

Following a study done by Lingnau (2011) where low starch supplements were fed to cows grazing ryegrass/kikuyu pastures. Kikuyu is high in neutral detergent fibre (NDF) compared to ryegrass and therefore, the aim of this study was to determine the effect of substituting maize with high fibre by-products in concentrates fed to Jersey cows grazing kikuyu pasture.

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CHAPTER 2

Literature review

2.1 Introduction

Dairy production systems differ worldwide as well as locally. Intensive total mixed ration (TMR) systems, which offer narrow profit margins, are being replaced by pasture based systems internationally (Khalili and Sairanen, 2000; Delahoy *et al*., 2003). Pasture based systems are able to produce milk at lower costs with a high output per ha of land (Clark and Kanneganti, 1998). Pasture forms the base for milk production in the Southern Cape region in South Africa (Meeske *et al.*, 2006). During the greater part of summer and autumn, kikuyu (*Pennisetum clandestinum*) is the most dominant pasture species (Botha *et al*., 2008b). Kikuyu is a C_4 pasture specie that is well adapted to the main milk producing area in the Western Cape Province of South Africa (Botha, 2003). Although kikuyu is highly productive during summer and autumn, winter and spring dry matter (DM) production is low. The forage quality of kikuyu is low and as the pasture growth season progresses, daily milk yield per cow is low and can drop by as much as 38% from December to May (Marais, 2001; Henning *et al*., 1995).

Pasture provides the cheapest feed source available to dairy cows and increasing the consumption of pasture will increase the profit margin (Clark and Kanneganti, 1998). The nutrient requirements of high producing dairy cows cannot be satisfied by only grazing high quality pastures (Dixon and Stockdale, 1999). Energy is the first limiting nutrient on a pasture based system which can be overcome by supplemental feeding (Kolver and Muller, 1998). Supplemental feeding can provide the limiting nutrients but will result in a reduction of pasture dry matter intake (DMI), through substitution (Minson, 1991).

The cost of supplements are continuously affected by the availability and price of raw materials. According to Meeske *et al*. (2006), dairy concentrates contribute up to 66% of the total feed cost in a pasture grazing system. Improving efficiency of production and reducing cost of supplements for dairy cows is becoming increasingly important for dairy farming systems.

Supplements that are high in fibre have increased pasture DMI and milk production (Meijs, 1986; Sporndly, 1991; Sayers, 1999). High fibre by-products can maintain a high ruminal pH, enhance pasture digestion and hence result in increased DMI (Bargo *et al.*, 2003). Bradford and Mullins (2012) stated that the replacement of grain with a non-forage fibre source is profitable in some scenarios and often increases DMI. Feeding by-products contributes valuable nutrients to diets and allows feedstuffs to be used that would otherwise be handled as wastes in landfills. Many of these by-products provide considerable amount of protein, non-forage fibre, fat and minerals to diets (Eastridge, 2006). Milk yield per cow continues to increase with a slower rate of increase in dry matter intake; thus, efficiency of ruminal fermentation and digestibility of the dietary components are key factors to improving the efficiency of feed use (Eastridge, 2006).

Milk payment schemes vary in relation to milk yield and milk components. With an increase in milk yield internationally and a volatile milk price, there is greater emphasis on the importance of milk fat and milk protein content.

2.2 Kikuyu pasture

2.2.1 Introduction

Kikuyu is a perennial grass, which grows actively during the spring and autumn months (Dickinson *et al.*, 2004). It performs best under irrigation and this makes it an extremely popular pasture to use in the Southern Cape region of South Africa (Tainton, 2000; Botha *et al.*, 2008b). The development of rhizomes below and stolons on top of the soil makes kikuyu a robust grass which can withstand frequent and heavy grazing (Tainton, 2000; Dickinson *et al.*, 2004). Due to the dormant nature of kikuyu during the winter months, it is commonly over-sown with a temperate grass, e.g. annual ryegrass, which grows actively during winter months.

Milk production from pasture is largely dependent on factors controlling herbage intake and ruminal digestion. The factors that influence herbage intake are numerous, but can be broadly described in terms of four areas: environmental, plant, animal and management factors.

2.2.2 Kikuyu morphology

Kikuyu (*Pennisetum cladestinum*) is a C_4 pasture species which is well adapted to areas of the Western Cape Province of South Africa (Van der Colf *et al*., 2009). Kikuyu is a robust, vigorous and creeping perennial that possesses strongly noded stolons (above ground) and rhizomes (below ground) (Quinlan *et al*., 1975). Kikuyu regularly propagates vegetatively from these vigorously spreading stolons that can form secondary stolons (Marais, 2001). The profusely branched stolons and rhizomes possess the ability to form roots at the nodes (Whyte *et al*., 1968; Mears, 1970). Short leafy branches are formed from stolons, with leaf blades strongly folded into a bud when young (Dickenson *et al*., 2004). The leaf surface of kikuyu is sparsely and softly hairy, the ligule characterised by a ring of hairs and the collar a prominent pale yellow colour. Under favourable moisture and soil conditions, the persistent sod of kikuyu can be highly productive, but a thick, stemmy mat can form under less favourable conditions (Whitney, 1974). Growth can be restricted in some instances by a lack of tolerance to cold and dry conditions (Marais, 2001). During summer and autumn months, in the Southern Cape, kikuyu is highly productive but the DM production is low during winter and spring (Van der Colf *et al*., 2009).

The natural distribution of kikuyu is limited to the upland areas of east central Africa, at altitudes of between 2000 to 3050 m above sea level (Whyte *et al*., 1968). Where the annual rainfall is approximately 1000 to 1600 mm (Mears, 1970). Kikuyu is an aggressive colonizer and under different circumstances it can be viewed as a weed, soil cover or pasture grass (Whitney, 1974).

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).

As can be seen from the data in Table 1, tropical grasses in the tropics and sub tropics, if well-watered and fertilised, can yield more dry matter per year as temperate species and have the potential to support higher grazing capacities (Minson *et al*., 1993). The higher dry matter production and grazing capacity of tropical grasses can be attributed to the greater efficiency of the photosynthetic pathway (C_4) and the higher light intensity in the tropics (Minson *et al*., 1993).

Table 1 Mean production and light energy conversion by well fertilised and watered temperate and tropical grasses (Minson *et al*., 1993)

	Temperate	Tropical	Difference (%)
No. of studies	6	17	-
Dry matter yield (t DM/ha per year)	22	49	125
Potential carrying capacity (cow/ha)	5,5	12	125
Light energy conversion (%)	2,3	3	30
Photosynthetic pathway	C_3	C_4	-

Kikuyu has a high annual DM yield potential with values of up to 28.2 t/ha per annum recorded in the literature for well-established kikuyu (Gherbin *et al*., 2007). Under very high nitrogen (N) fertilisation rates of 874 kg N/ha per annum, Whitney (1974) reported yields of 35 t/ha per annum for kikuyu, stating that yields could probably be further increased with higher N fertilisation rates. The range in annual DM yields recorded for kikuyu by various authors is given in Table 2. The large variation in DM yields reported by various authors in the literature is most likely due to differences in management, local environment, soil and climatic conditions at different sites.

Kikuyu is well known for its seasonality in DM production (Marais, 2001). The most active growth period in kikuyu occurs from summer to autumn (Cook and Mulder, 1984; Hacker and Evans, 1992; Andrews and Jagger, 1999), whilst growth rates are lowest during winter (Mears and Humphreys, 1974; Andrews and Jagger, 1999) and spring (Fulkerson *et al*., 1993; Botha *et al*., 2008a). The growth rate of kikuyu in spring at 33.9 kg DM/ha per day can be as low as half of the summer growth rates of 67.0 kg DM/ha per day (Botha *et al*., 2008a), with as much as 50% of total annual DM yield occurring in the summer months (Gherbin *et al*., 2007). The commencement of kikuyu growth during spring is dependent on the availability of adequate moisture and nitrogen for the kikuyu during this period (Hartridge, 1969).

Table 2 The range of annual dry matter (DM) yield recorded for kikuyu in literature

Reference	Annual DM yield (t DM/ha per annum)
Whitney 1974	35
Pearson *et al*. 1985	15,1
Evans and Hacker 1992	7,1
Hacker and Evans 1992	6,24
Andrews and Jagger 1992	10 - 16
Fulkerson *et al*. 1999	7,8 - 12,1
Cruywagen *et al*. 2007	13,1
Gherbin *et al*. 2007	28,2
Botha *et al*. 2008a	13,1

Various other tropical species have been reported to out-yield kikuyu, but kikuyu tended to possess a higher forage density and leaf density (Hacker and Evans, 1992), a higher proportion of leaf and a higher leaf yield (Pearson *et al*., 1985). Pasture yield alone may, however, be a poor indicator of kikuyu productivity because the creeping growth form of kikuyu makes ground level difficult to define. As a result, a small variation in cutting height will result in large variation in yield (Andrews and Jagger, 1999). In addition, quality rather than yield, is the primary limitation to annual production from pasture based on C_4 grasses (Fulkerson *et al*., 1999).

2.2.3 Pasture utilization and management

Many factors affect dry matter intake on pasture. These include the pre-grazing pasture mass, expressed as the amount of pasture per unit area (kg DM/ha) as well as the pasture allowance. Pasture allowance (PA) is the amount of pasture allocated to a cow per day, expressed as kg DM/cow per day (Bargo *et al.*, 2003). Pasture allowance is usually estimated at 30 mm above ground level because it is accepted that the material below that height is not available for grazing (Dillon, 2006).

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 twice a day could have greater benefits.

2.2.4 Pasture intake

Pasture intake can be estimated by using direct or indirect methods. Direct methods may have more accurate results but they are laborious, invasive to the animal and costly. The rising plate meter (RPM) is a measuring instrument based on the Ellinbank pasture meter that was earlier developed by Earle and 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.*, 1996; 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 increase 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

According to Stockdale (2000) and Peyraud and 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).

The response in milk production of dairy cows to different forms and levels of supplementation can be seen in Table 3. Reeves *et al*. (1996) found that as the level of concentrate increased, the milk production per cow increased, while Fulkerson *et al*. (2006) did not report any significant improvement. Animal production from kikuyu can be improved using energy supplementation (Marais, 2001). Fulkerson *et al*. (2006) reported a decreased utilisation efficiency of the roughage component in the diet as the proportion of concentrate increased. As the level of concentrate fed to dairy cows grazing kikuyu increased, intake and pasture digestibility decreased and substitution rate increased (Fulkerson *et al*., 2006). The daily milk yield and milk protein content (%) of cows grazing kikuyu increased as the metabolizable energy (ME) content in the concentrate increased (Reeves *et al*., 1996). Butterfat content (%) of milk was however found to decrease as the ME content of the concentrate increased.

Table 3 The milk production (kg/cow per day) and composition (%) obtained from animals grazing kikuyu when supplemented with various types and amounts (kg/day) of concentrate (Van der Colf *et al*., 2009)

Reference	Breed	Concentrate		Milk production	Composition	
		Type	Amount		Butterfat %	Protein %
Reeves *et al*., 1996	Holstein	unsupplemented	0	14.2	3.77	3.06
		barley based	3.0	18.3	3.51	3.22
		barley based	6.0	18.0	3.26	3.19
Fulkerson *et al*., 2006	Holstein	dairy pellets	2.0	26.75	3.66	3.16
		dairy pellets	3.8	24.75	3.83	3.20
		dairy pellets	5.9	24.50	3.67	3.26

The total food intake increases by feeding energy supplements when there is abundant forage available for grazing although pasture intake is reduced (Minson, 1991). Substitution can be defined as a decrease in DMI from pasture due to an intake of supplements for part of the pasture they would have consumed (Stockdale, 2000; Bargo *et al.*, 2003).

According to Dixon and 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 reduced 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 Substitution rates

The substitution rate (SR) is positively correlated with the level of concentrate fed. As stated by McEvoy *et al*. (2009), substitution rate is the decrease in forage DMI per additional kg of concentrate supplement. As such feeding a supplement leads to lower intake of pasture and is referred to as substitution rate (Grainger and Mathews, 1989; Faverdin *et al*., 1991; Stockdale, 2000; Sairanen *et al*., 2006). This is undesirable as pasture is the cheapest source of feed and is then not utilised efficiently (Faverdin *et al*., 1991; Clark and Kanneganti, 1998; Stockdale, 2000; Bargo *et al*., 2003; Sairanen *et al*., 2006). Bargo *et al*. (2003), proposed a formula with which to calculate substitution rate: substitution rate (kg/kg) = [(Pasture DMI on unsupplemented treatment – Pasture DMI on supplemented treatment) / Supplement DMI]. 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 and Stockdale (1999), or by a reduction in grazing time as ascribed by McGilloway and Mayne (1996).

Substitution rate is problematic as it results in variation in milk response to supplementation and on a short term basis the milk response to supplementation is what determines whether the supplementation is economically viable (Grainger and Mathews, 1989; Bargo *et al*., 2003). To determine the long term effects of supplementation, the body condition of cows as well as milk composition must be monitored (Bargo *et al*., 2003).

2.4.1 Pasture-related factors affecting substitution rate

The species, height and quality of pasture all determine the substitution rate as well as stocking rate of cows (Stockdale, 2000; Bargo *et al*., 2003; Sayers *et al*., 2003; Macdonald *et al*., 2008).

As the level of concentrate feeding increases the level of pasture allowance should decrease, resulting in an increase in the stocking rate (Faverdin *et al*., 1991; Vazquez and Smith, 2000). In such a situation pasture will be grazed more effectively, enforcing maximum pasture intake and avoiding pasture losses, optimising farm profitability (Stockdale, 2000; Bargo *et al*., 2003; Macdonald *et al*., 2008).

Tozer *et al*. (2004) also found an increase in substitution rate as the supplement level was increased but the substitution of pasture was less severe under high stocking rates. Therefore one way of overcoming substitution of pasture is by increasing stocking rates and thereby improving the efficiency of pasture utilisation (Vazquez and Smith, 2000; Bargo *et al*., 2003; Tozer *et al*., 2004; McEvoy *et al*., 2009). Lowering stocking rates results in increased pasture allowance which results in a higher substitution rate (Bargo *et al*., 2002b).

2.4.2 Supplement related factors affecting substitution rate

The amount and type of supplementation fed to cows will determine the rate of substitution but the correlation between level of supplement fed and substitution rate still remains inconclusive (Bargo *et al*., 2003). Studies have shown that when 2 - 6 kg DM/d is supplemented there are no negative effects on pasture intake (Kellaway and Porta, 1993). Although it has also been found that substitution rate increases as supplementation rate increases, even if supplement level remains below 6 kg DM/day (Bargo *et al*., 2003; Sayers *et al*., 2003).

Stockdale (2000) found that substitution increased by 0.21 kg DM pasture/kg DM concentrates for each additional kg of DM intake of pasture/ 100 kg of liveweight. According to Bargo *et al*. (2003) and Kellaway and Harrington (2004) the rate of degradation of concentrate supplement in the rumen will affect substitution rate. Concentrate supplements that are more rapidly degraded (e.g. ground cereal grain) increase substitution rate, as opposed to supplements that are less easily degraded and remain in the rumen for longer (e.g. protein supplement or whole cereal grain) which decrease substitution rate (NRC, 2001; Bargo *et al*., 2003; Kellaway and Harrington, 2004; Sairanen *et al*., 2006). Concentrate supplements that are more rapidly degraded result in a rapid decrease in rumen pH, lowering the activity of cellulolytic bacteria and a subsequent decrease in the rate of fibre digestion (Kellaway and Harrington, 2004). The decreased rate in fibre digestion lengthens the passage rate of feed, decreasing pasture intake and increasing substitution rate (Kellaway and Harrington, 2004).

Meijs (1986), Delahoy *et al*., (2003) and Sayers *et al*., (2003) found that substitution rate decreased when non-forage fibre based supplements where fed whereas Stockdale (2000) found that feeding non-forage fibre based supplements actually increased the substitution rate by 0.08 kg DM per kg supplement. The increased substitution rate in response to a non-forage fibre based supplement is due to decreased grazing time, more time spent consuming supplement and more time spent ruminating (Stockdale, 2000). The decrease in substitution rate as reported by Meijs (1986), Delahoy *et al*., (2003) and Sayers *et al*., (2003) can be explained by taking the effect that supplements have on rumen pH into account. High fibre supplements maintain rumen pH and ensure optimum activity of cellulolytic enzymes, which results in lower rumen fill and stimulate increased DMI of pasture (Meijs, 1986; Bargo *et al*., 2003).

It is clear that the effect of supplement on substitution rate varies widely and that both supplement level and supplement type must be taken into account to accurately predict DMI of pasture.

2.5 Nutrient requirements of Jersey cows on pasture

The nutrient requirements of pasture based Jersey cows will depend on milk production, milk composition, maintenance and pregnancy requirements and the BCS of the cow (Kolver, 2003).

2.5.1 Energy requirements

The NRC (2001) refers to the energy required for lactation as net energy for lactation (NEL) and it includes requirements for maintenance, milk production and replenishment of lost weight. During early lactation feed intake is low and unable to maintain high levels of milk production, as such body reserves are mobilised. During mid-lactation intake is sufficient to maintain milk production. During late lactation milk production declines, but intake remains high, this allows for the build-up of body reserves, in preparation for the next lactation. As energy is the first limiting nutrient on pasture, it is essential to supplement cows on a pasture based system so as to ensure high milk production as well as sufficient deposition of body reserves throughout the lactation cycle (Kolver and Muller, 1998).

2.5.2 Protein requirements

The rate of proteolytic activity in the rumen depends on the solubility and susceptibility of compounds to microbial proteases and the time spent in the rumen (Parker *et al*., 1995). The release of peptides, AA, organic acids, ammonia (NH_3) and carbon dioxide from the hydrolysis of protein and NPN compounds, all provide a source of N for microbial protein synthesis (Church, 1983; McDonald *et al*., 2002; Parker *et al*., 1995). The N compounds digested in the rumen all enter the rumen NH_3 pool where it is then either incorporated into microbial cells, absorbed through the rumen wall into the portal blood or passed through to the abomasum in ruminal fluid (Church, 1983; Rook and Thomas, 1983; Parker *et al*., 1995). Some small peptides and free AA are also utilised, along with the NH_3, for microbial protein synthesis (McDonald *et al*., 2002). The NH_3 pool in the rumen is essential for ensuring rumen health and optimal degradation of carbohydrates (McDonald *et al*., 2002; Rook and Thomas, 1983).

Two factors that limit milk production on pasture are low DMI (Bargo *et al*., 2003) and a high concentration of highly degradable CP in relation to NSC (Carruthers and Neil, 1997). The CP of temperate pasture species, such as ryegrass, typically exceed the recommendations of the NRC (2001) of 16 % - 18 % CP for high producing cows (Carruthers and Neil, 1997). This results in a high concentration of NH_3 in the rumen which cannot be fully utilised by the micro-organisms in the rumen, is not converted into microbial protein and does not contribute to milk production (Carruthers and Neil, 1997). Providing cows with readily fermentable carbohydrates will assist with the utilisation of NH_3. The time of feeding of readily fermentable carbohydrates is extremely important as they need to be degraded in synchronisation with protein in pasture (Trevaskis *et al*., 2004). This will ensure that micro-organisms have sufficient energy at their disposal for efficient degradation of protein.

Pasture does not supply sufficient RUP for the synthesis of milk (Sairanen *et al*., 2005). It is essential to include a protein source high in RUP in a concentrate supplement fed to high producing cows on pasture (Bargo *et al*., 2003; Sairanen *et al*., 2005; Fulkerson *et al*., 2007).

2.5.3 Neutral detergent fibre requirements

The term NDF refers to the residue found after extraction of forages with boiling neutral solutions (sodium lauryl sulphate), heat resistant α-amylase and ethylene diamine tetra-acetate (EDTA) (Van Soest *et al*., 1991). The residue is made up of lignin, cellulose and hemicellulose (Van Soest *et al*., 1991; NRC, 2001; McDonald *et al*., 2002). Neutral detergent fibre can be used to quantify differences between various feed sources (e.g. grasses vs. legumes, forages vs. concentrates) (Mertens, 1997). The correct ratio of forages to concentrates in a diet is essential for ensuring the optimal production of dairy cows (Mertens, 1997). Neutral detergent fibre is used to quantify the upper limit of this ratio, but NDF does not take the physical characteristics of fibre associated with the kinetics of digestion and passage rate into account (Mertens, 1997).

The composition of feed affects the microbial population in the rumen and as a result changes the profile of fermentation products (Bauman and Griinari, 2003; Zebeli *et al*., 2012). Lipid synthesis in the mammary gland is dependent on the volatile fatty acid (VFA) profile in the rumen (Bauman and Griinari, 2003; Kellaway and Harrington, 2004). Acetate and butyrate are the primary VFA produced from the fermentation of fibre and provide the main carbon source for de novo fatty acid synthesis, whereas propionate is produced through the fermentation of rapidly fermentable carbohydrates (Van Soest *et al*., 1991; McDonald *et al*., 2002; Bauman and Griinari, 2003). When the inclusion level of rapidly fermentable carbohydrates is increased to the detriment of NDF inclusion levels, to try and improve milk production, there is not only a decrease in pH but the profile of VFA produced in the rumen changes as well. The production of propionate increases with a resultant decrease in acetate and butyrate production, fewer precursors are available for de novo fatty acid synthesis in the mammary gland and milk fat decreases (Kennelly and Glimm, 1998). According to Stockdale (1999) 25 - 35 % NDF is required to maintain milk fat content and rumen function. Mertens (1997) coined the term ‘effective NDF’ or eNDF, which is a measure of the ability of NDF to maintain milk fat content.

2.5.4 Physically effective neutral detergent fibre requirements

The term peNDF specifically refers to the structural feature of fibre which stimulates salivation and as a result helps to maintain rumen function and ensure the efficient utilisation of nutrients (Allen, 1997; Mertens, 1997; Zebeli *et al*., 2012). Therefore the physical effectiveness of fibre depends on the ability of fibre to form a rumen mat which will stimulate rumination (Welch, 1986; Van Soest *et al*., 1991; Allen, 1997; Mertens, 1997). The ability of fibre to stimulate rumination depends on the physical characteristics of the fibre, primarily particle length (Allen, 1997; Mertens, 1997). Fibre particles are also essential in the reticulorumen where they act as a filtering system and slow the passage rate of particles; further adding to increased digestion of fibre (Welch 1986; Van Soest *et al*., 1991; Lammers *et al*., 1996; Yang and Beauchemin, 2009).

Poppi *et al*. (1980) determined that the critical particle length of particles to be retained in the reticulorumen is 1.18 mm. The original Penn State Particle Separator (PSPS) developed by Lammers *et al*. (1996) only included two sieves with mesh sizes of 19.1 mm and 7.87 mm. A third sieve with a 1.25 mm mesh was added later. The PSPS is a simple, practical device that separates particles of different lengths, allowing amongst other things, for the prediction of peNDF.

Normal rumen function is related to adequate rumination and maximum cellulose digestion (Van Soest *et al*., 1991). Long periods of low ruminal pH are characteristic of sub-acute ruminal acidosis which is detrimental to rumen health as well as digestion of feed (Shriver *et al*., 1986; Yang and Beauchemin, 2009). The pH of the rumen is integral to ensuring the activity of cellulolytic micro-organisms, the subsequent production of propionate and acetate which are essential for lipid metabolism in lactating cows as well as the supply of microbial AA to the small intestine (Van Soest *et al*., 1991). Diets meeting the nutritional guidelines for NDF and peNDF will promote rumen health and as a result increase digestibility and improve the efficiency of utilisation of nutrients (Yang and Beauchemin, 2009). The time spent on rumination per day is directly proportional to the level of peNDF consumed per day, relative to body size (Welch and Smith, 1969; Lammers *et al*., 1996). Visual observations of cows during the day will provide an idea of the overall health; a ruminating animal is a healthy animal.

Milk fat content will also decrease when diets high in NDF but low in peNDF are fed (Lammers *et al*., 1996; Bauman and Griinari, 2003; Plaizier *et al*., 2009). Under these circumstances the diet is unable to stimulate rumination and secrete saliva to maintain the pH balance and as a result the microbial population changes (Bauman and Griinari, 2003, Plaizier *et al*., 2009). The activity of cellulolytic bacteria will decrease, further decreasing the production of acetate and butyrate and lowering milk fat production (Van Soest *et al*., 1991; McDonald *et al*., 2002; Bauman and Griinari, 2003).

Finding the balance between sufficient levels of peNDF so as to maintain rumen health while still feeding high energy products to maintain production has been a major challenge of the high producing dairy industry (Yang and Beauchemin, 2009; Zebeli *et al*., 2012). This problem is magnified in a pasture based system where the time lapse between consumption of high energy concentrates in the milking parlour and intake of pasture after milking often results in a rapid decrease in pH which will ultimately inhibit the digestion of feed (Trevaskis *et al*., 2004).

2.6 Feeding sufficient fibre for dairy cows on pasture

The upper limit of NDF which should be included in the diet is a function of the energy requirement of the animal; ruminants consuming diets high in NDF often are unable to eat sufficient quantities to meet their energy demands. There is a maximum level at which non-fibrous carbohydrates can be fed while still maintaining microbial activity and the negative effect that high levels of NDF have on DMI and subsequent production (Jung and Allen, 1995; Allen, 1997; NRC, 2001). The lower limit of NDF which should be included in the diet depends largely on rumen and cow health and mostly refers to peNDF (Allen, 1997; NRC, 2001).

The NDF guidelines are based on total NDF of diet as well as % of NDF from forage (NRC, 2001). Forage sources include any feedstuff that is composed of stems and leaves and is fed as fresh material, hay or silage (NRC, 2001). The effectiveness of non-forage NDF (eNDF) sources is determined by the response of milk fat content (Allen, 1997). On the other hand, the effectiveness of forage NDF (peNDF) sources is determined through monitoring the rumen pH. The specific guidelines of the NRC (2001) for NDF inclusion can be seen in Table 2; these guidelines were designed for dairy cows on a TMR system and therefore cannot be blindly applied to cows on a pasture based system.

From Table 2 the relationship between NFC and forage NDF can be seen clearly. As the level of NFC inclusion increases the % of NDF which must be obtained from forage increases as well. The forage NDF is required to stimulate rumination and salivation, which will in turn help to increase the pH of the rumen and prevent the onset of acidosis due to the rapid fermentation of NFC. The total dietary NDF inclusion level is also linked to the NFC level. As mentioned above, the NDF level of inclusion depends on the NEL requirement of the animal and as such the more NFC included the closer the NEL requirements are to being met and the less need there is for NDF as an energy source for milk production.

Milk production is lower on a pasture based system than on a TMR system (NRC, 2001; Bargo *et al*., 2002a). High quality pastures are characterised as having 40 - 50% NDF and 18 - 25% CP, which indicates that they are more highly digestible and generally provide less peNDF (Bargo *et al*., 2002a; Bargo *et al*., 2003; Plaizier *et al*., 2009). High quality pastures combined with higher levels of concentrate feeding may not provide adequate peNDF and as a result the pH of the rumen and the ratio of acetate to propionate decreases and the passage rate of feed increases (NRC, 2001; Bargo *et al*., 2002a). Pasture typically contains 5 - 30% NFC which is lower than the 35 % recommended feeding level for lactating cows (Carruthers and Neil, 1997).

2.7 Regulation of intake

The consumption of a feed is limited by the physical capacity of the rumen and rumen fill depends on the digestibility of the feed, which in turn is determined by the fibre concentration (Hoover, 1986; Kendall *et al*., 2009). Therefore the digestibility of a feed will determine the level of intake. When the digestibility of a feed is below 67%, as in a high fibre concentrate supplement, the physical capacity of the rumen, more specifically distension of the reticulo-rumen, will determine the DMI (Allen, 2000; NRC, 2001; Adin *et al*., 2009). The cessation of intake due to the physical capacity of the rumen being reached is in response to stretch and tension receptors lining the muscular wall of the rumen (NRC, 2001; McDonald *et al*., 2002). When digestibility of the diet is above 67%, DMI is controlled through the chemostatic regulation of blood metabolites, specifically the VFA absorbed from the rumen (NRC, 2001; McDonald *et al*., 2002; Adin *et al*., 2009). Allen (2000) determined that when the NDF concentration of a diet exceeds 25%, DMI will be negatively affected. The extent of this correlation depends on the fibre source (forage vs. non-forage source) as well as the NDF digestibility (Allen, 2000). Non-forage fibre has a smaller "filling" effect than forage fibre but it also has a higher digestibility, which indicates that intake of a non-forage fibre source is controlled both by physical capacity as well as by chemostatic regulation (Allen, 2000).

2.8 Starch vs fibre based supplements

In a study performed by Miron *et al.* (2004) it was found that replacing up to 25% of maize grain with a non-forage fibre source (e.g. soy hulls or wheat bran) increased milk fat content and milk production and had no negative effects on milk protein content. One of the potential negative effects of a non-forage fibre based supplement is the lowered DMI. Meijs (1986), Delahoy *et al.* (2003) and Sayers *et al.* (2003) found that substitution rate of pasture decreased when non-forage fibre based supplements where fed whereas Stockdale (2000) found that feeding non-forage fibre based supplements actually increased substitution rate (2.10.2).

Delahoy *et al.* (2003) and Sayers *et al.* (2003) found that cows grazing a medium quality pasture will benefit more from a concentrate based supplement, whereas cows grazing high quality pasture will benefit more from a non-forage fibre based supplement. The fact that pasture quality and animal requirements change throughout the year complicates the process of supplying the correct balance of nutrients. The ideal would be to use three to four different types of supplements and feed them accordingly throughout the year (Sayers *et al*., 2003). There are no guidelines to providing the correct NDF to cows on pasture and the NDF requirements for cows on pasture are simply adapted from the NRC (2001) NDF requirements for cows on a TMR system (Table 2). The NRC (2001) does describe the energy requirements for increased activity on pasture based systems.

2.8.1 By-products

Feeding a more ruminally degradable carbohydrate such as steam-flaked maize to lactating dairy cows grazing pasture did not affect DMI, milk production, or milk composition. However, steam-flaked maize resulted in lower plasma and milk urea nitrogen, suggesting an improved N utilization compared with cracked maize when cows grazed good quality pasture (<50% NDF, >65% IVDMD). Feeding non-forage based supplements instead of maize-grain based supplements had no effect on DMI, milk production, or milk composition of mid-lactation dairy cows grazing medium quality pasture (>50% NDF, <65% IVDMD), although a trend for higher milk fat percentage existed. Maize grain supplementation increased milk protein percentage and decreased MUN, suggesting that cows fed maize based supplements utilized N more efficiently than cows fed the non-forage based supplement. This also suggested that supplementation with starch-based concentrates may be more beneficial with medium quality pastures, while supplementation with fibre-based concentrates may be more beneficial with high quality pastures.

In the manufacture of starch and glucose from maize, a number of by-products are obtained which are suitable for feeding farm animals. The three by-products (germ, bran and gluten) are frequently mixed together and sold as maize gluten feed. Dark brown material indicates heat damage, which will decrease the digestibility of the protein. Since it is a milled product, the fibre will not have the same effect as a long roughage in ruminant diets.

2.8.2 Hominy chop

A by-product of white maize milling, containing germ and maize husks with a small amount of endosperm. The quality varies according to milling processes. A good quality hominy chop should contain about 9 % fat. Most of the energy comes from the oil, with a small amount of starch making up the balance. It is not suitable as total maize replacement in high energy rations. Rancidity can be a problem in storage and depressed butterfat percentages in the milk can occur (Evans and Johnson, 1995).

2.8.3 Wheat bran

The wheat grain consists of about 82 % per cent endosperm, 15 % bran and or seed coat and 3 % germ. During the milling process, the endosperm is separated from the bran and germ. Wheat flour is derived from the endosperm and used for human consumption whereas the high fibre bran and germ are by-products from this process that can be used as animal feeds (McDonald *et al*., 2002).

2.8.4 Gluten

Maize gluten feed is a moderately high source of protein, more than cereal grains and milling by-products. Maize gluten is richer in cell wall constituents than maize grain and has a low lignin content of about 1.2 % DM. The crude fat content is usually under 4 % DM. The composition of maize gluten feed is influenced by the proportion of steep liquor, which contains more energy and protein than bran (Scott *et al*., 1997). Maize gluten feed varies in colour from yellow-light brown to dark brown depending on temperature and drying time. Dried gluten feed generally darkens with increased drying temperature and drying time. Extremely dark gluten feed with a burned smell may be heat damaged and the protein digestibility may be reduced (Schroeder, 2010; Myer *et al*., 2011). Gluten is low in calcium but has relatively high levels of phosphorus and potassium (Maiga *et al*., 1997).

2.8.5 Soya bean oilcake

Soya beans contain from 160 to 210 g/kg of oil and are normally solvent-extracted. The residual meal has an oil content of about 10 g/kg. The residual content is known as the oilcake. According to Evans and Johnson (1995), the oil content is about 10 g/kg but the protein content is commonly 450 g/kg or more, compared to about 380 g/kg in the whole bean. Palatability can be a problem when inclusion levels exceed 20 g/kg of a ration.

2.9 Production parameters

The milk production of dairy cows has been found to respond positively to concentrate supplementation (Tozer *et al*., 2004). Dry matter intake of high quality pastures, however, rather than ME content, has been identified as the major factor limiting the energy supply from pasture (Kolver and Muller, 1998). For this reason, cows grazing pasture should be supplemented with energy dense concentrates to achieve their genetic milk production potential and in order to reduce the need to mobilize excessive amounts of body reserves in early lactation (Kolver and Muller, 1998; Bargo *et al*., 2003; Pedemera *et al*., 2008). Of interest, Tozer *et al*. (2004) did not report an improvement in feed conversion efficiency (in terms of milk production) of supplemented cows compared to cows grazing only pasture. Supplementation of forages with grain or sugar is intended to increase the overall energy intake of the animal (Meissner, 1997). Providing additional energy in the form of supplementation has often produced reductions in the intake of grazed forages, whilst it can also affect pasture digestibility (Caton and Dhuyvetter, 1997; Toxzer *et al*., 2004). Fulkerson *et al*. (2006) reported that in dairy cows grazing kikuyu pasture there was an 8 % decrease in pasture digestibility for every 9 % increase in concentrate intake proportion of the diet. The supplementation of grazing animals with high energy feeds results in a depression of cell wall digestibility, which leads to a marginal increase in total energy consumption (Meissner, 1997). Although Fulkerson *et al*. (2006) reported that cows were prepared to utilise more pasture as the proportion of concentrate increased and that the efficiency of use of the roughage component did not decrease as this occurred. When attempting to identify a milk response from supplementation with energy dense concentrates of dairy cows, consideration should however be given to the inherent energy content of pasture (as influenced by botanical composition and maturity). Stockdale (1999), for example, found that as the metabolisable energy content of pastures increased and the fibre content decreased, the milk response of dairy cows receiving high energy supplements decreased.

Milk fat decline is one of the major economic disadvantages of producing milk from pasture, with the effect particularly pronounced in lush temperate pastures with a low fibre content (Polan *et al*., 1985). A possible reason for the low milk protein reported in cows grazing pasture, compared to cows fed TMR, has been identified as an efficient utilisation of ingested N, most likely because a large proportion of amino acids is partitioned towards gluconeogenesis (Kolver and Muller, 1998). As a result, animals grazing pastures will show an increase in milk protein levels when supplementation levels increase (Lehman *et al*., 2007). The milk fat concentration (%) of cows grazing pasture has been found to decrease as the amount of energy concentrate fed increases (Polan *et al*., 1985), while fat yield (kg fat/cow) has been reported to increase, primarily due to the increase in milk yield when dairy cows grazing pastures are supplemented (Tozer *et al*., 2004). Stockdale *et al*. (2001) and Lehman *et al*. (2007) were however of the opinion that cows grazing good quality pastures can ingest relatively large quantities of high-energy supplements before milk fat depression occurs. The partial replacement of maize and soybean oilcake with high fibre by products, such as hominy chop, maize gluten and bran, was found to increase the milk fat concentration (%) of dairy cows grazing annual ryegrass pastures (Meeske *et al*., 2009). Meeske *et al*. (2009) therefore concluded that by lowering the starch content of dairy concentrate, the milk fat content and 4 % FCM production of supplemented dairy cows grazing pastures could be increased. Reeves (1997) also found that the inclusion of a $NaHCO_3$ (which would reduce the decline in rumen pH associated with high starch cereal concentrates) prevented the reduction in pasture digestibility that results from barley supplementation.

Appropriate strategies for supplementation of high producing dairy cows requires an understanding of the effect of different types of supplements on dry matter intake, animal performance and digestion, as well as providing nutrients that compliments the nutrient content of the available pasture (Bargo *et al*., 2003). Although supplementation is a useful tool in improving milk production from pastures, maintenance of high forage quality and high forage utilisation by correct pasture management is a must to maintain profitability of concentrate feeding within a pasture based dairy system (Stewart *et al*., 1995).

Data from grazing studies at Moorepark suggest that for each kg increase in milk yield (over the range 15 – 30 kg milk/day) cows will consume an extra 0.4 – 0.5 kg DM/day (Stakelum, 1993). The challenge in maintaining the high merit cow at grass, is to seek to arrest the decline in intake due to sward and animal behaviour constraints that restrict intake, by manipulating grassland management and supplementation strategies (McGilloway and Mayne, 1996).

The rate at which grass grows is dependent on the environment, the nutrients available and the amount of leaf within the sward which is intercepting light. Immediately after grazing, there is a period of slow regrowth followed by an accelerated rate and finally a period of decreasing growth as the herbage matures (McDonald *et al*., 2002). Typical growth rates for temperate pastures in the spring are 40-100 kg DM per ha per day.

2.9.1 Milk yield

Dry matter intake constraints are one of the major limitations for milk production in grazing systems (Smith *et al.*, 2005b), rather than energy content of pasture (Kolver and 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 and Sairanen (2000) reported increased milk production 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

(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. 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).

2.9.2 Milk fat

The majority of the grazing studies reported no effect on milk fat percentage when fibre-based concentrates replaced starch-based concentrates (Meijs, 1986; Khalili and Sairanen, 2000; Delahoy *et al.*, 2003; Gehman *et al.*, 2006). However, three studies reported increased milk fat percentage ($P < 0.05$) 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 and 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.* (2008) stated that peNDF is strongly associated with milk fat yield and ruminal pH. This is supported 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, while 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. 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.

2.9.3 Milk protein

Meijs (1986), Khalili and 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. 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 and 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 and McGuire (2006) stated that when readily fermentable carbohydrates (RFC) are fed to cows; it is expected that cows will produce more milk protein due to increased propionate and microbial protein production.

2.9.4 Lactose

Khalili and 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 and Sairanen (2000), with no alteration in milk lactose percentage.

A study done by Gibson (1989) found that the milk lactose concentration average for Jersey cows is in the region of 4.7%. Welper and 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 and Glimm, 1998). Jenkins and 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 and Freeman, 1992).

2.9.5 Somatic Cell Counts

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).

2.9.6 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, 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 and 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. 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).

2.9.7 Body Weight and Body Condition Score

None of the authors cited in Table 3 reported any differences in BW change between starch-based and fibre-based concentrates. 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 herds and within 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.

2.10 Rumen parameters

2.10.1 Anatomy, physiology and microbiology

Ruminants have a unique digestive system that can break down forages and fibrous roughages that cannot be broken down by monogastric digestive enzymes (McDonald *et al*., 2002). The bacteria in the rumen secrete the enzymes that are necessary for cellulose degradation which makes it possible for ruminants to utilize roughage (Visser, 1995). The stomach of the ruminant is divided into four compartments; rumen, reticulum, omasum and abomasum. The rumen and the reticulum, the first two compartments, are often discussed together as they are adjoining compartments. The rumen and reticulum are relatively undeveloped in the young suckling ruminant. A tube-like fold, known as the oesophageal or reticular groove, channels the milk to the third and fourth compartments, the omasum and abomasum. As the young lamb or calf begins to eat solid food, the rumen and reticulum enlarge until they comprise of 85% of the total capacity of the stomach. In the adult, the reticular groove does not function, unless stimulated, and both food and water pass into the rumen. The food is diluted with saliva, first during eating and again during rumination: typical amounts of saliva produced per day are 150 litres in cattle and 10 litres in sheep. Rumen contents exist in two phases: the lower liquid phase, in which the finer food particles are suspended, and a drier upper layer of coarser solid material. During rumination, material at the anterior end is drawn back into the oesophagus and returned by a wave of contraction to the mouth. Any liquid is rapidly swallowed again, but coarser material is thoroughly chewed again before returning to the rumen. The tactile stimulation of the epithelium in the anterior rumen is the main reason for rumination. Diets low in coarse roughage may fail to stimulate rumination. The time spent on rumination depends on the fibre content of the food (McDonald *et al.*, 2002).

Fermentation in the rumen produces acids which reduce the pH of rumen liquor. Saliva contains phosphate and bicarbonate which act as buffers to stabilise the pH in the rumen (McDonald *et al.*, 2002).

Rumen microorganisms consist of bacteria, protozoa and fungi. Bacteria are the most abundant and require substrate to produce end products of fermentation. The total number of bacteria and the relative population of individual species vary with the animals' diet; for example, diets rich in concentrate foods promote high total counts and encourage the proliferation of *lactobacilli*. Protozoa are present in much smaller numbers but are larger and may equal bacterial total mass. Protozoa are responsible for ingesting food particles but cannot utilize cellulose. The role of fungi in the rumen is yet to be fully established. They are strictly anaerobes and consist of two phases, the motile (zoospore) and vegetative phase (sporangium). During the motile phase they become attached to food particles by rhizoids, which can penetrate cell walls. The rumen fungi are capable of utilising most polysaccharides and many soluble sugars. Fungi are most numerous when diets are rich in fibre (McDonald *et al.*, 2002).

2.10.2 Rumen pH

Rumen pH is one of the most variable factors which can influence the microbial population and the levels of volatile fatty acids produced (Ishler *et al.*, 1996). There are two basic groups of bacteria which function at various levels of pH. The fibre digesters are most active at a pH 6.2 to 6.8. Cellulolytic bacteria and methanogenic bacteria can be reduced when the pH begins to fall below 6.0. The starch digesters prefer a more acidic environment, a pH of 5.2 to 6.0. Certain species of protozoa can be greatly depressed with a pH under 5.5. To accommodate all of these needs, normal feeding strategies should maintain a pH range of 5.8 to 6.4.

Hoover (1986) stated that it is important to maintain rumen pH within a narrow range to ensure optimal fibre digestion in the rumen. The recommended optimum pH level for fibre digestion in the rumen differs between authors and their findings. Dixon and Stockdale (1999) suggested that the optimal pH range for fibre digestion in the rumen is 6.6 to 7.0, whereas Pitt *et al.* (1996) and Kolver *et al.* (1998) suggested a range of 6.0 to 6.9 for optimal fibre digestion in the rumen. According to Hoover, (1986), Sutton *et al.* (1986) and Dixon and Stockdale, (1999), fibre digestion in the rumen is inhibited when rumen pH drops below 6.0. Complete cessation of fibre digestion in the rumen occurs when pH drops below 5.0 (Mould *et al.*, 1984). Acute and subacute rumen acidosis can be defined by a pH below 5.0 and below 5.6 respectively (Owens *et al.*, 1996).

Fibre digestion in the rumen is affected by several other factors than just the rumen pH. The extent of pH depression and the time that pH remains below 6.0 should also be considered in affecting fibre digestion (Ørskov and Istasse, 1983). Beauchemin and Rode (1999) supported this by adding that a perpetual low rumen pH is needed to decrease fibre digestion in the rumen. Extreme daily variation in rumen pH can be just as harmful to the microbes in the rumen by altering their metabolic functions (Mertens, 1979). The post feeding drop in rumen pH is a result of feeding concentrates that are high in RFC (Dixon and Stockdale, 1999). According to Yang *et al.* (2001), starch fermentation in the rumen has a more pronounced effect on rumen pH than that of the physical characteristics of feedstuffs. Rumen pH is highest before concentrate feeding and lowest after feeding, more specifically 2 to 5 h post concentrate feeding (Bargo *et al.*, 2002b; Nordlund and Garrett, 1994; Nocek, 1997; Cajarville *et al.*, 2006). Coleman *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.

2.10.3 Volatile Fatty Acids

The volatile fatty acids (VFA) produced by bacterial fermentation in the rumen are used by the cow to provide 50 to 70 % of her daily energy requirements and to form nearly 50 % of the butterfat produced by the mammary gland (Dugmore, 1995). Of all VFA produced in the rumen, 80 to 90 % are absorbed directly across the rumen wall, reticulum and omasum (McDonald *et al.*, 2002). The remaining VFA are utilised by rumen microrganisms or passed through to the abomasum and small intestine (Kenelly and Glimm, 1998; McDonald *et al.*, 2002). Usually, actetate, propionate and butyrate account for more than 95% of the VFA found in rumen fluid (Bannik *et al*., 2006). The type of VFA produced is dependent on the change in diet and is important to quantify as acetate and butyrate are primary precursors for long-chain fatty acid synthesis whereas propionate is primarily used as a precursor for glucose. In general, more starch fermentation will increase propionic acid production, whereas more cellulose fermentation will increase acetic acid production (Baldwin, 1995).

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 and Sairanen (2000) reported no change in the principle VFA's. 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.

Bach *et al.* (1999) found that the acetate proportion increased in response to increased fibre intake, whereas Zebeli *et al.* (2008) reported that the acetate proportion responded negatively to increased non-structural carbohydrate intake. 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.

2.10.4 Rumen ammonia nitrogen (NH_3)

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. However, both Khalili and 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.

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 minimum ruminal NH_3-N concentration for maximum microbial protein synthesis is 5 mg/dl 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.

2.10.5 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. Lingnau (2011) also found no effect on *in situ* ruminal digestion of ryegrass by replacing a starch-based concentrate with a fibre-based concentrate.

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 and 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 maize-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.

2.10.6 Digestibility

Providing cows on pasture with a concentrate supplement high in readily fermentable carbohydrates results in a decrease in rumen pH, which negatively impacts the activity of proteolytic and cellulolytic micro-organisms. Decreased activity of micro-organisms will result in a lower rate of digestion of pasture, ultimately lowering DMI and milk production (Berzaghi *et al.*, 1996). Feeding a concentrate supplement high in a non-forage fibre source will not have such a negative effect on pH but a decrease in digestibility of pasture is still seen (Berzaghi *et al.*, 1996). The decrease in digestion of pasture is as a result of a change in the micro-organism profile of the rumen, cellulolytic micro-organisms activity is repressed and fibrolytic micro-organisms activity escalates (Berzaghi *et al.*, 1996).

In a study by Bargo *et al.* (2002b) providing cows on pasture with a concentrate supplement decreased the rate of DM digestion of pasture as well as the rate of NDF digestion of pasture. In a study by Lingnau (2011) feeding a low starch concentrate supplement did not improve the rate of digestion of pasture or the extent of digestion of pasture compared to a high starch concentrate supplement. Calsamiglia *et al.* (2002) found that a cyclic drop in pH or a continuously low pH lowered the rate of digestion compared to a drop in pH experienced twice a day and lasting for only one hour, as would be the case on a pasture based system where cows receive a concentrate supplement. The lowered digestibility as a result of concentrate supplement feeding is not ideal but still does not outweigh the advantages of feeding a concentrate supplement.

2.11 Conclusion

In South Africa, pasture-based systems are lower cost systems compared to the total mixed ration system. This being said, the first limiting nutrient on pasture is energy which can be overcome by supplementation with dairy concentrates. The dairy concentrates can contribute up to 66% of the feed cost in the pasture-based systems. Starch is the most common form of energy that is supplemented in the form of maize. Maize is, however, expensive as well as high in readily fermentable carbohydrates (RFC) which could have a negative effect on rumen health by lowering the pH of the rumen. The rumen environment changes with changes in the diet which can be seen after concentrates have been fed to cows grazing pasture. Fibre digesting bacteria are active at higher pH’s in the rumen which means that supplementation with concentrates could reduce fibre digestion and cause substitution.

A previous study done on ryegrass pasture (Lingnau, 2011) showed that maize could be partially substituted with high fibre by-products in concentrates fed to Jersey cows. The partial substitution of maize with hominy chop, wheat bran and gluten 20, makes the concentrate cheaper, reduces the RFC and increases the NDF. With kikuyu being higher in NDF than ryegrass, the purpose of this study was to determine the effect of high fibre concentrates on milk yield and composition as well as rumen health when fed to Jersey cows grazing kikuyu pasture during Summer.

2.12 References

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CHAPTER 3

Effect of feeding a high fibre supplement to Jersey cows grazing kikuyu pasture on milk production and milk composition

3.1 Introduction

There were two components to this research study, namely a lactation production study and a fundamental rumen study using rumen cannulated cows. These two studies were run at the same time. The production study will be described in this chapter followed by the rumen study in Chapter 4. The study was conducted at the Outeniqua Research Farm situated near George in the Western Cape. The aim of the production study was to determine the effect of feeding a high fibre concentrate to Jersey cows grazing kikuyu pasture on milk production, milk composition, body weight as well as body condition score.

3.2 Materials and methods

3.2.1 Location and duration of the study

The study was conducted on the Outeniqua Research Farm near George in the Western Cape Province of South Africa (33°97.961' S; 22°41.926' E; altitude 204 m). The mean annual rainfall for this region from 2007 to 2012 was 815 ± 276 mm per annum. The mean rainfall for the mid to late summer period 28th January to the 5th April from 2007 to 2013 was 131 ± 52 mm. The total rainfall for the duration of the trial (28th January to 5th April 2013) was 125 mm. The average maximum and minimum temperatures during the trial were 24.8 and 14.1°C respectively.

3.2.2 Experimental design

Fifty-one high producing multiparous Jersey cows were selected from the Outeniqua Research Farm herd. Cows in their first lactation, as well cows out of the range of 30 to 190 DIM, were excluded from the trial due to the variability in milk production often experienced from such animals, as well as to avoid calving during the trial period. The fifty-one cows were then blocked according to milk yield, days in milk and lactation number. Cows within blocks were randomly allocated (random function in Microsoft excel, 2010) to three treatments (low, medium and high fibre) resulting in seventeen cows per treatment. Refer to Table 14 in appendix A for more detail. The rumen study comprised of six lactating rumen cannulated cows which were randomly allocated to the low and high fibre treatments (3 cows each). Additionally, 3 cows were selected from the large herd and placed in the medium fibre treatment group as non-participant cows. Each group consisted of 20 cows due to the fact that in the dairy parlour, cows are fed and milked in groups of 20. This is a practical constraint of the milking system.

Cows grazed kikuyu pasture as one group for 24h per day except during milking times when they received their concentrate supplement in the milking parlour. The cows were collected prior to milking and returned as quickly and efficiently as possible in a calm and collected approach. The cows allocated to each treatment group had different colour tags attached to chains around their neck. Before each milking session, cows were separated into the three treatment groups. Cows entered the milking parlour in their separate groups and received the correct concentrate. The routine was maintained throughout the trial period as cows adapt and respond to a routine allowing easier management.

Table 4 The mean and standard deviation of milk yield, milk fat from previous lactations, 4% fat corrected milk (FCM; as of the 12th December 2012), days in milk (DIM; as of the 15th January 2013), lactation number and body weight of each treatment after blocking (n=17)

Parameter[1]	**Treatment**		
	Low Fibre	**Medium Fibre**	**High Fibre**
Milk yield (kg/cow/day)	19.8 ± 2.2	19.6 ± 1.9	19.6 ± 1.9
Milk fat (g/kg)	46.6 ± 2.80	46.1 ± 3.00	46.5 ± 3.30
FCM (kg/cow/day)	21.7 ± 2.7	21.4 ± 2.4	21.5 ± 2.3
DIM (d)	95.5 ± 41	91.5 ± 47	87.7 ± 40
Lactation nr.	3.88 ± 1.7	3.94 ± 1.1	3.88 ± 1.6
BW (kg)	387 ± 30	384 ± 23	386 ± 29

[1]DIM – days in milk; FCM – fat corrected milk; BW – body weight

3.2.3 Feeding and milking program

The experimental treatments are shown in Table 5. Maize was partially replaced by hominy chop, wheat bran and gluten 20. This resulted in concentrates with lower starch and higher digestible fibre contents. The supplements were formulated on an *iso*-nitrogenous basis with a CP content of 12.3 % (DM) in all three supplementary treatments. Soybean oilcake was reduced to maintain an *iso*-nitrogenous concentrate. The differences in ME values can be attributed to the decrease in maize concentration.

Table 5 Composition of the three concentrates used for experimental treatments fed to Jersey cows grazing kikuyu pasture during summer

Ingredient[1] (g/kg of DM)	**Concentrates**		
	Low Fibre	**Medium Fibre**	**High Fibre**
Maize	785	508	227
Hominy chop	0	175	350
Wheat bran	0	90	180
Gluten 20	0	60	120
Soybean oilcake	131	88	45
Molasses	40	40	40
Feed lime	18	19	22
MCP	8	3	0
Salt	10	10	10
MgO	3	2	1
Premix[2]	5	5	5
Nutrient[3] (g/kg of DM or as stated)			
DM	868	864	862
CP	123	123	123
ME (MJ/kg DM)	11.5	11.2	10.9
NDF	76.5	134	191
Fat	32.1	40.7	49.2
Calcium	8.6	8.4	9.1
Phosphorus	4.0	4.0	4.5
Magnesium	3.3	3.2	3.2

[1]MCP – mono-calcium phosphate; MgO – magnesium oxide
[2]Premix – $6x10^6$ IU Vitamin A; $1x10^6$ IU Vitamin D3; $8x10^3$ IU Vitamin E; 4 g/kg copper; 10 g/kg manganese; 20 g/kg Zinc; 340 mg/kg iodine; 200 mg/kg cobalt; 60 mg/kg selenium
[3]DM – dry matter; CP – crude protein; ME – metabolisable energy; NDF – neutral detergent fibre

Kikuyu pasture was allocated *ca.* 10 kg DM/cow/day above 30 mm (RPM reading of 6) which was calculated using a standard seasonal regression: Y = (H x 70) – 420, where 'Y' = herbage DM yield (kg DM/ha) and 'H' = recorded height of RPM. This regression was derived from seasonal regression equations determined by Van der Colf (2011) to be used for pre- and post –grazing estimations. An after-grazing height of 50 mm (RPM of 10) was maintained by adjusting the allocated kg DM pasture per cow based on the DM yield per hectare calculated using the generalised regression.

Cows within a treatment group were fed the allocated treatment diet throughout the experimental period. A 14 day adaptation period was followed by a 54 day trial period during which data was collected. Cows were milked twice a day at 05:30 and 14:00 and received 3 kg (as is) of supplemented concentrate at each milking, totalling 6 kg (as is) of concentrate per day. The concentrate was weighed out beforehand into plastic bags and then manually placed into the feeding troughs to ensure each cow received the correct amount and correct type of concentrate. The feed troughs were thoroughly cleaned before each feeding by sweeping out all the refusals.

3.2.4 Data collection

3.2.4.1 Feed samples

Over the ten week study period (two weeks adaptation period and 8 weeks experimental period), three grab samples were taken from each concentrate per week and pooled fortnightly. The pooled sample was thoroughly mixed in order to obtain a representative sample of each concentrate. A grab sample was then taken from the pooled sample and placed into a plastic container, sealed and kept for later analysis. A total of four samples were collected for each concentrate over the eight week experimental period.

3.2.4.2 Pasture samples

Pasture samples were taken on a weekly basis during the experimental period. An iron ring, the same diameter as the plate meter, with a height of 30 mm above ground level was randomly placed in the pasture at three different sites. All plant material within the ring was cut to a height of 30 mm above ground level and placed in a paper bag. The three pasture samples were weighed and dried for 72hr at 60° C and then weighed again to determine the pasture DM content. At the end of the 8 week experimental period, the dried pasture samples from each week were milled through a 1 mm sieve using a SMC hammer mill (www.smc.org.za/hammermill.htm) and stored in plastic containers for later analysis. A total of 8 pasture samples were collected during the experimental period.

3.2.4.3 Pasture regression

Pasture cuttings were done on a weekly basis in front of the cows (next grazing strip). Areas of high, medium and low pasture heights were identified relative to the area that was to be grazed next. At each height (low, medium and high) a disc meter reading was taken, the metal ring placed on that spot and the grass was then cut to a 30 mm height. The grass cut from inside the ring was then placed into a paper bag, weighed, dried for 72 h at 60°C and then weighed again. Three cuttings and measurements were recorded at each height. The dry weight and the area that was cut (0.0985 m^2 in this case) were used to determine the kg of DM per hectare with the following equation: kg DM/ha = dry weight (g) / 0.0985 m^2 x 10 000 m^2/ha / 1000 g/kg. The disc meter reading height was plotted against kg DM/ha using Excel to obtain a regression equation.

3.2.4.4 Milk yield and milk samples

Milk yield for each cow was recorded electronically at morning and afternoon milking on a daily basis by the Dairy Master Computer software in a 20 point swing over milking machine (Total Pipeline Industries, 33 van Riebeeck Street, Heidelberg, 6665). Milk samples were taken fortnightly during the experimental period, i.e. four sampling times. A representative amount of milk per cow was siphoned off into a separate container during milking. The fat composition of milk differs between morning and afternoon milking, to overcome this, morning and afternoon milk samples were combined to form a composite sample. The interval between morning and afternoon milking was 8 hours, and 16 hours between afternoon and morning milking times. In order to obtain a representative sample, an 8ml sample was taken in the afternoon and 16 ml was taken in the morning. Each milk sample bottle contained a Potassium dichromate ($K_2Cr_2O_3$) tablet which was used as a preservative.

Milk samples were sent to Lactolab (Irene), Pretoria, for analysis. Milk samples were analysed for milk fat, protein, lactose, milk urea nitrogen (MUN) and somatic cell count (SCC).

3.2.4.5 Body weight and body condition scoring (BCS)

All participant cows were weighed at the beginning and at the end of the study over two consecutive days. To reduce variation, weighing took place after morning milking each time and two weights were recorded and averaged to reduce variation due to pasture intake, defecation and urination. Body condition scoring (BCS) was done at the same time as weighing for all experimental animals. BCS was scored on a five point scale (Mulvany, 1977) and because BCS is done subjectively, each scoring was done by the same person to minimise variation.

3.2.5 Analytical methodologies

3.2.5.1 Feed and pasture sample analysis

The four feed samples and eight pasture samples were analysed in duplicate for DM (AOAC, 2002; method 934.041), ash (AOAC, 2002; method 942.05), CP (AOAC, 2002; method 990.03; using the LECO N analyser, model FP-528), NDF (Robertson and van Soest, 1981; using the Ankom fibre analysis system), ADF (Robertson and van Soest, 1981; Ankom fibre analysis system), NDIN (samples were first analysed for NDF, residue was then analysed for

N on the Leco N analyser), ADIN (samples were first analysed according to the ADF procedure, residue was then analysed for N on the Leco N analyser), EE (AOAC, 2002; method 920.39), GE (CP00 Bomb calorimeter), *IV*DMD (Buys et al., 1996) and starch (Karkalas, 1985). Metabolisable energy (ME) was calculated as follows: ME = GE x *IV*DMD x 0.84 for concentrates and ME = GE x *IV*DMD x 0.81 for forages (ARC, 1984). Organic matter (OM) was calculated as follows: OM = 100 - % Ash. Calcium, phosphorus and potassium were analysed in the plant science laboratory at Elsenburg, Stellenbosch, Western Cape.

The hot weighing technique was used on all samples and crucibles where applicable and was followed during analysis. Windham (1986) found no significant difference between the hot weighing technique and the desiccator technique when determining moisture content. The hot weighing technique did however show a higher accuracy (SEM = 0.8g/kg) than the desiccator technique (SEM = 1.1g/kg).

3.2.5.2 Milk samples

The preserved milk samples were transported overnight to Lactolab (ARC, Irene, Pretoria) where they were analysed for: milk fat, protein, lactose, MUN and SCC. Milk fat, protein and lactose were analysed using Fourier Transform Spectrometer technology. MUN was analysed using the ChemSpec 150 and SCC was analysed with the Somacount FCM by means of flow cytometry.

3.2.5.3 Statistical analysis

The experimental design was a randomised block design with three treatments (low fibre, medium fibre and high fibre) allocated to 17 blocks (cows per treatment). 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. A Student's t-test was used to compare the treatment means and a significance of difference ($P \leq 0.05$) between means was determined by Fishers test (Samuels, 1989). Least square means (LSMEANS) was used to calculate a pooled standard error of treatment means (Statistical Analysis Systems Institute, 2012).

3.3 Results and discussion

3.3.1 Nutrient composition of concentrates and pasture

Table 6 represents the actual nutrient composition of the sampled feed of each treatment concentrate that was allocated to the cows during the study period as well as pasture.

Table 6 Mean and standard deviation of the nutrient composition of each of the three concentrates (n = 4) and the pasture (n = 8) fed to Jersey cows during the study

Nutrient[1] (g/kg of DM or as stated)	**Treatment**			**Pasture**
	Low Fibre	**Medium Fibre**	**High Fibre**	
DM	910 ± 0.01	910 ± 0.01	910 ± 0.01	151 ± 19.7
Ash	66.2 ± 0.8	67.4 ± 1.5	69.1 ± 2.4	95.5 ± 8.6
OM	934 ± 0.8	933 ± 1.5	931 ± 2.4	905 ± 8.6
CP	140 ± 2.1	144 ±1.5	145 ± 0.7	201 ± 21.6
EE	25.2 ± 4.7	39.7 ± 1.7	51.6 ± 1.2	29.2 ± 6.0
NDF	94.3 ± 3.6	154 ± 1.5	226 ± 3.1	571 ± 43.6
NDIN	-	-	-	25.7 ± 3.
ADF	28.4 ± 1.0	46.3 ± 0.4	67.6 ± 2.3	269 ± 15.7
ADIN	-	-	-	13.5 ± 3.6
*IV*DMD	97.2 ± 0.6	93.6 ± 1.1	87.1 ± 0.9	69.1 ± 7.6
Starch	490 ± 20.8	413 ± 36.7	319 ± 0.9	-
GE (MJ/kg DM)	17.7 ± 0.08	17.8 ± 0.3	18.3 ± 0.2	18.5 ± 0.1
ME (MJ/kg DM)	14.4 ± 0.05	14.0 ± 0.3	13.4 ± 0.2	10.4 ± 1.1
Calcium	12.5 ± 0.5	12.5 ± 0.6	12.1 ± 0.6	5.30 ± 0.5
Phosphorus	5.92 ± 0.1	6.22 ± 0.1	6.7 ± 0.2	5.01 ± 0.5
Ca:P ratio	2.10 ± 0.06	2.00 ± 0.08	1.79 ± 0.07	1.07 ± 0.1
Potassium	8.90 ± 0.2	9.95 ± 0.1	11.4 ± 0.5	34.2 ± 6.2

[1]DM – dry matter; OM – organic matter; CP – crude protein; EE – ether extract; NDF – neutral detergent fibre; NDIN – neutral detergent insoluble nitrogen; ADF – acid detergent fibre; ADIN – acid detergent insoluble nitrogen; *IV*DMD – *in vitro* dry matter digestibility; GE – gross energy; ME – metabolisable energy

The concentrates were formulated to be *iso*-nitrogenous (123 g/kg of DM) as shown in Table 5, whereas there is slight variation in CP content (140 g/kg, 144 g/kg and 145 g/kg) between the low, medium and high fibre treatments respectively. The NDF levels (94.3 g/kg, 154 g/kg and 226 g/kg), as well as the starch concentration (490 g/kg, 413 g/kg and 319 g/kg) reflects the substitution of maize with high fibre concentrates.

3.3.2 Pasture management

The kikuyu pasture dry matter (DM) yield per hectare above a 30 mm height was estimated using the linear regression. The regression equation is in the form of y = mx + c, where y is the DM yield per hectare and x is the height of the RPM. The regression was calculated to be y = 84.67x + 78.20 with a R^2 of 0.769.

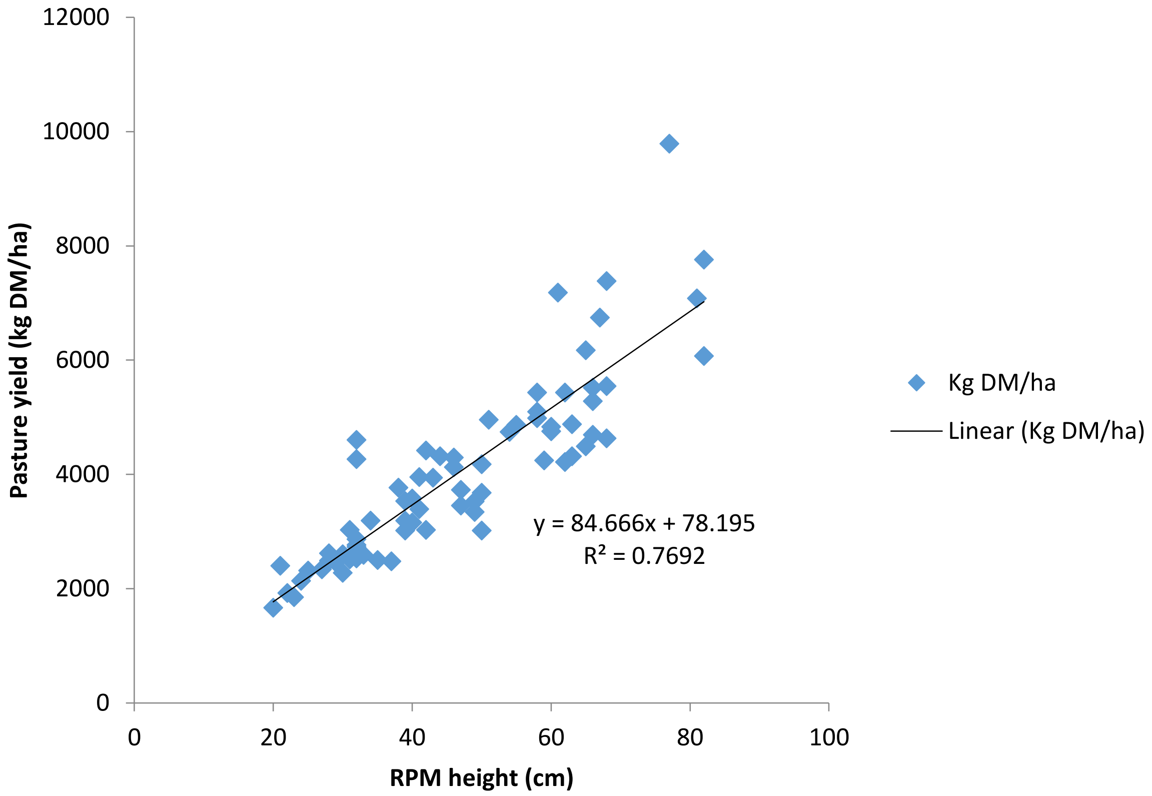

Figure 1 The relation between the rising plate meter height and dry matter yield of kikuyu pasture over the duration of the study as well as the regression developed for this relationship

The RPM is inaccurate in determining individual pasture DMI (Reeves *et al.*, 1996); 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 allocation for the grazing cow. The residual grazing height on the RPM should be 10-12 (50 mm – 60 mm). This ensures that pasture was not over or under grazed.

Cows were allocated a new strip of pasture after each milking period, resulting in a shortened grazing time on each strip that increases the reliability of the RPM (Smith *et al.*, 2005). The grazing rotation was 27 days for the allocated area for the study.

3.3.3 Pasture quality

Pasture quality parameters affected by the progression from mid to late summer of kikuyu pasture samples collected over the eight week study period are depicted in Figure 1. The ME and IVDMD of the pasture decreased whereas the NDF seemed to increase as the season progressed. The ADF, CP, DM and EE seemed to remain stable throughout the study period. Several authors reported that pasture quality decreases as the season progresses (Bargo *et al.*, 2003; Meeske *et al., 2006;* Fulkerson *et al*., 2007; Van der Colf, 2011; Steyn, 2012). According to Carruthers and Neil (1997), 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. The marginal variability of CP could be due to N fertilization which was set at 42 kg N/ha after each grazing during this study. The ADF levels are well above the recommended 19 to 21 % ascribed by the NRC (1989) to prevent milk fat depression.

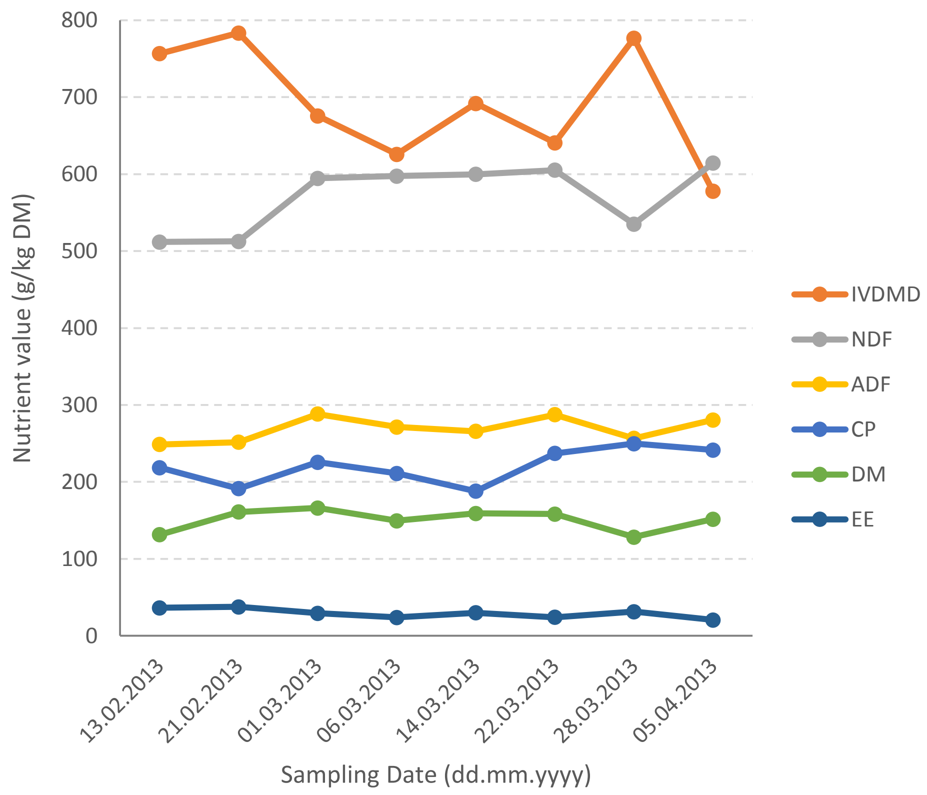

Figure 2 Pasture quality parameters affected by the progression from mid- to late Summer of Kikuyu pasture samples collected over an eight week period during the study

3.3.4 Milk yield

Milk production parameters are shown in Table 7. The milk yield and 4 % fat corrected milk (FCM) did not differ between treatments. This is in accordance with several authors who found no significant effect on milk production when high fibre supplements were compared to low fibre supplements (Kibbon and Holmes, 1987; Spörndly, 1991; Fisher *et al*., 1996; Sayers *et al*., 2003). Miron *et al.* (2004) and Lingnau (2011) both confirmed that milk production was sustained when maize was replaced with non-forage fibre sources such as hominy chop and wheat bran compared to a diet with no inclusion of a non-forage fibre source. In the studies done by Meijs (1986) and Meeske *et al*. (2009), there were no significant differences in milk yield although these authors found the fat corrected milk to be significantly higher for the high fibre supplement. Khalili and Sairanen (2000) reported an increase in milk production when cows were fed a mixture, formulated form a range of ingredients, compared to supplementing barley on its own. 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.

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 was 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). Although the high fibre concentrate was lower in ME, 13.4 MJ/kg DM, compared to the medium, 14.0 MJ/kg DM, and low fibre, 14.4 MJ/kg DM, concentrates, it can be postulated that the milk production was sustained due to an increased pasture DMI. This hypothesis was not tested on account of the cows grazing as one group and DMI was calculated as an average for the group. In the review done by Bargo *et al*. (2003), they proposed that ruminal pH and pasture digestion would increase when starch-based concentrates are replaced with fibre-based concentrates and therefore resulting in a higher DMI. In this study, the pH and the pasture digestion (Chapter 4) did not differ between treatments.

3.3.5 Milk Fat

The milk fat % in this study showed no significant differences between treatments which is contrary to the results from Meeske *et al.* (2009) who indicated a significant difference in milk fat percentage between low fibre and high fibre supplementation. According to Lingnau (2011), the high fibre treatment had a higher milk fat percentage than the low fibre treatment. Most authors, however, found no effect on milk fat percentage between low and high fibre supplementation on pasture based systems (Meijs, 1986; Kibbon and Holmes, 1987; Schwartz *et al.*, 1995; Khalili andSairanen, 2000; Sayers *et al.*, 2003).

3.3.6 Milk protein

Milk protein of cows on the low fibre treatment was higher than that of cows on the high fibre treatment. The medium fibre did not differ from the low or the high fibre treatments in terms of milk protein %. Several authors found no significant differences in milk protein between low and high fibre supplementation for grazing dairy cows (Meijs, 1986; Gibbon and Holmes, 1987; Schwartz *et al.*, 1995; Fisher *et al.*, 1996; Khalili and Sairanen, 2000; Meeske *et al.*, 2009). The main factor contributing to milk protein content is the ME content of the total ration (Schwartz *et al.,* 1995). The lower milk protein content in the high fibre treatment could be explained by the lower ME content of the high fibre supplement compared to the higher ME concentration and RFC of the low fibre supplement which yielded a higher milk protein %.

According to Delahoy *et al.* (2002), maize supplementation increased milk protein percentage and decreased MUN, suggesting that cows fed maize based supplements utilized N more efficiently than cows fed the non-forage based supplement. Delahoy *et al.* (2002) also suggested that supplementation with starch-based concentrates may be more beneficial with medium quality pastures, while supplementation with fibre-based concentrates may be more beneficial with high quality pastures. The treatments were formulated on an iso-nitrogenous basis and all cows grazed the same pasture indicating that CP content of the diet was not a contributing factor.

3.3.7 Milk lactose

Lactose did not differ between the low and medium fibre treatments, while the lactose was lower in the high fibre treatment. According to Sutton (1989) and Kennelly and Glimm (1998), lactose is the least variable component of milk and remains around 4.7 – 4.8 % (Gibson, 1989; NRC, 2001) regardless of diet or breed; a change in lactose content was not expected. Most authors found no effect on lactose content of the milk between low starch and high starch supplements (Kibbon and Holmes, 1987; Spörndly, 1991; Fisher *et al*., 1996). Khalili and Sairanen (2000) found milk lactose yield to be higher for grazing dairy cows with low fibre supplementation. Lactose is related to milk yield which probably explains the higher lactose yield yet the lactose percentages remain similar. One of the factors that could result in a change in lactose content is the SCC or health of the udder (Kitchen, 1981; Welper and Freeman, 1992).

3.3.8 Milk urea nitrogen

There was no significant difference in milk urea nitrogen content between treatments in this study. The observations also agreed with those of a similar study done by Meeske *et al*. (2009). The MUN content of the three treatments were within the acceptable range of 8 – 16 mg/dL (Logix, 2013). Although, according to De Villiers *et al.*, (2000), the MUN content of the three treatments in this study are low with the acceptable range being 12 – 18 mg/dL. According to Delahoy *et al*. (2002), maize supplementation increased milk protein percentage and decreased MUN, suggesting that cows fed maize based supplements utilized N more efficiently than cows fed a non-forage fibre-based supplement. Lower MUN values could indicate a high level of highly fermentable carbohydrates for utilisation of rumen ammonia or a lack of protein, with the latter being the unlikely cause.

3.3.9 Somatic cell count

The SCC did not differ between the low and medium fibre treatments and was highest in the high fibre treatment ($P < 0.05$). The SCC in all treatments were, however, below the acceptable range of 500 000/ml as stipulated in the South African law (Regulation 1555 of the Foodstuffs, Cosmetics and Disinfectants Act, No 54 of 1972), below the 400 000/ ml as required by the European Union for export and below 300 000/ ml which is considered abnormal and indicative of subclinical mastitis (De Villiers *et al.*, 2000). The differences in SCC are usually as a result of individual cow health rather than a response to the treatments. The lower lactose content in the high fibre treatment can possibly be explained by the higher SCC level in the high fibre treatment.

Table 7 Mean milk yield, milk composition and BW and BCS change of Jersey cows (n = 17) grazing kikuyu pasture and fed 6 kg (as is) of low, medium and high fibre concentrates during summer

Parameter[1]	Treatment			SEM[2]	P-value
	Low Fibre	Medium Fibre	High Fibre		
Milk Yield (kg/cow/day)	18.8	18.9	18.3	0.35	0.35
4% FCM	19.2	19.2	18.9	0.41	0.84
Milk Fat (%)	4.18	4.14	4.27	0.09	0.62
Milk protein (%)	3.66[a]	3.53[a,b]	3.45[b]	0.05	0.01
Milk lactose (%)	4.73[a]	4.73[a]	4.49[b]	0.05	<.001
MUN (mg/dL)	10.2	10.3	9.26	0.33	0.11
SCC (x 1000/mL)	141[a]	145[a]	230[b]	28.6	0.06
BW start (kg)	387	383	386	4.83	0.88
BW end (kg)	400	395	394	5.11	0.63
BW change (kg)	+13.0	+11.4	+8.12	2.47	0.37
BCS start (scale 1 - 5)	2.06	2.06	2.03	0.03	0.77
BCS end (scale 1 - 5)	2.41	2.40	2.32	0.05	0.38
BCS change (scale 1 - 5)	+0.35	+0.34	+0.29	0.04	0.50

[1]FCM – fat corrected milk; MUN – milk urea nitrogen; SCC – somatic cell count; BW – body weight; BCS – body condition score
[2]SEM – standard error of the mean
[a, b] Means in the same row with different superscripts differ ($P < 0.05$)

3.3.10 Body weight and body condition score

The BW and BCS did not differ between treatments. There was also no difference in BW change and BCS change over the study period which indicates that the cows did not utilise body reserves to maintain milk production and the supplements provided sufficient energy to maintain milk production. Similar results have been found in several studies where starch-based concentrates were compared to fibre based concentrates (Sayers *et al.*, 2003; Meeske *et al.*, 2009; Lingnau, 2011). According to Bargo *et al.* (2002) BW is not subject to change in such a short study period as would compromise a feeding study.

3.4 Conclusion

Milk production, milk fat content and MUN were not affected by the partial substitution of maize with high fibre by-products. As the maize was substituted with high fibre by-products, the ME content of the concentrate decreased. Although the high fibre concentrate had a lower energy content, the milk yield was sustained with no differences in BCS between treatments. The protein content in the milk was however lower in the high fibre treatment which could negatively affect the milk price when the milk buyer pays according to solids.

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CHAPTER 4

Effect of feeding a high fibre supplement to Jersey cows grazing kikuyu pasture on rumen parameters and rumen health

4.1 Introduction

Two studies were conducted simultaneously, namely a production study and a rumen study. The production study was described in Chapter 3, whereas the rumen study will be described in this chapter. The rumen study was conducted to determine the effect of feeding a high fibre supplement to Jersey cows grazing kikuyu pasture on rumen parameters and rumen health.

4.2 Materials and methods

4.2.1 Location and duration of the study

The location and duration of the rumen study was the same as what had been described for the production study in section 3.2.1.

4.2.2 Animal welfare

Ethical clearance was obtained through the Western Cape Department of Agriculture and the DECRA approval number was R12/86.

4.2.3 Experimental design

Six ruminally cannulated cows were selected from the Outeniqua Research Farm herd. The cannulated cows were randomly allocated (random function in Microsoft Excel, 2010) to the low fibre and the high fibre treatments, resulting in three cannulated cows in both treatments. Cows were subjected to a two period cross-over design. Each period consisted of an eighteen day adaptation period and a nine days data collection period. A cross-over design duplicates results and subjects cows to both treatments over the duration of the study. The cannulated cows grazed, were milked and were fed the same as the cows in the production study. The only difference between the two groups of cannulated cows was the low and high fibre treatment concentrates that they received, as the other factors were the same for all the cows in the study.

4.2.4 Feeding and milking program

The cannulated cows were fed and milked with the production study cows, as indicated in section 3.2.2.

4.2.5 Data collection

4.2.5.1 Rumen pH

Rumen pH was measured using TruTrack pH Data Loggers (Model pH-HR logger with M12 Pt 100 probe, Intech Instruments LTD, New Zealand). TruTrack pH data loggers allow for continuous recording of rumen pH for the duration of the two rumen sampling periods in the cross-over design. Prior to insertion into the rumen, loggers were calibrated with buffer solutions (pH 4, 7 and 9) using the Omnilog Data Management Program (Version 1.64). Each logger was clearly numbered and randomly allocated to the six cannulated cows. Each of the six cows received the same logger in both periods of the rumen study to limit variation. On the morning of insertion, loggers were started on the Omnilog Program and the electrodes were rinsed with distilled water before insertion. The logging system recorded the average pH in 10 min intervals for four days. The loggers were removed, washed, dried and the data downloaded and saved in an Excel file. The data sets were reduced to 30 min intervals by taking the average of every three 10 min intervals at and after the specified time, followed by calculating the mean over the four days.

4.2.5.2 Rumen fluid samples

Rumen fluid samples were taken on day four of the data collection period at 04h00, 12h00 and 20h00. Approximately 100 ml of rumen fluid was collected from each cow at each sampling time using a hand drain pump. The rumen fluid was drawn from the rumen digesta by inserting a 500 mm aluminium rod (5 mm in diameter) into the rumen that was connected to a hand pump via a rubber tube. The aluminium rod was moved slowly up and down in the rumen, taking care not to damage the rumen wall, while the action of the pump sucked the rumen fluid into an attached, clearly marked bottle. The pH of the rumen sample was taken immediately with a portable handheld pH logger (WTW pH 340i fitted with a WTW Sentix 41 pH electrode; Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany), after which the bottle was sealed and placed to one side. After samples had been taken from each cow, the rumen fluid samples were taken to the on- farm laboratory. Rumen fluid was filtered through 4 layers of cheese cloth to remove solid particles.

From each cow's filtered rumen fluid, two samples were taken. The one sample contained fifteen ml of rumen fluid only, pending VFA analysis. The other sample was made up of fifteen ml of rumen fluid and 2.5 ml of 50% H_2SO_4, pending NH_3-N analysis. After transferring the rumen samples into clearly labelled sampling bottles, the samples were frozen and stored in a freezer at -20° C until later analysis.

4.2.5.3 In situ pasture degradability

The NDF and DM digestibilities were determined using the *in sacco* Dacron bag technique described by Cruywagen (2006). Approximately 10 kg (as-is) of kikuyu pasture was cut at a stubble height of 30 mm. The kikuyu grass was then dried in brown paper bags at 60° C for 72 h (Botha, 2003). The dried grass was pooled and cut into 5-10 mm segments (Taweel *et al*., 2004).

Dacron bags (10 x 20 cm inner size; 53 µm pore size; Bar Diamond Inc, P.O. Box 60, Parma, Idaho, USA) were clearly marked and dried at 60° C overnight. Each bag was weighed directly from the oven on a three decimal scale (Sartorius L420P scale, with 0.001 g accuracy). The weight of each bag was recorded and on a tared scale, approximately 5 g of the dried, cut sample was accurately weighed out into the bag. The dacron bags were tied with cable ties, extra pieces cut off, and weighed once more on a tared scale. Three blank bags were prepared that did not undergo incubation but were washed with the other bags. Two bags were prepared per cow for each incubation time of 2, 4, 8 and 16 h and three bags per cow for each incubation time of 30, 72 and 96 h. The DM content of the cut kikuyu herbage was determined to enable accurate calculation of the DM weighed into each bag.

The receptacle and catcher technique, described by Cruywagen (2006), was used to facilitate the incubation and removal of *in situ* nylon bags from the rumen. The bags were tied into three legs of 44 decitex ladies stockings (not the antimicrobial type). Each cow would then have 17 prepared dacron bags with 5 g of dried and cut kikuyu grass in 3 legs of stockings (two legs with 6 bags and the other with 7 bags). A large marble was placed in the toe-end of each leg of stocking to act as an anchor and to ensure the bags penetrated the rumen contents. The stockings were fastened to a metal ring on the inside of the cannula plug.

The seventeen bags in three stocking legs were inserted into the rumen at 06h00, two bags were removed after 2, 4, 8 and 16 hours of incubation and three bags were removed after 30, 72 and 96 hours of incubation. After each removal time, the bags were transported to the on- farm laboratory, where the bag number, cow name and removal times were recorded. The bags were then rinsed with running cold water and stored in a freezer at -20° C for later use. At the end of the second period, all the bags were removed from the freezer and left to thaw in cold water. They were then transferred to a washing machine with cold water, approximately one quarter full to ensure that all the bags were submerged. The 0 hour bags that did not undergo incubation were treated in the same way and were washed together with the bags that had been incubated. The washing machine was turned on a gentle setting with no spinning and the bags were washed three times for 3 min cycles. After each cycle, the water was drained and replaced with clean water.

After washing, the bags were placed on a rack to drip dry in order to remove excess water before being dried in an oven at 60° C for 72 h. Each bag was weighed directly from the oven (hot weight) on the same scale that was used for weighing samples prior to incubation. After weighing, the bags were stored in a large bag in a freezer at -20° C pending NDF analysis.

4.2.6 Analytical methods

4.2.6.1 Rumen liquor samples

The NH_3-N content of the rumen liquor samples was determined using the procedure described by Broderick and Kang (1980). The VFA profile of the rumen liquor samples was determined using the HPLC method. Samples were subjected to a 'clean-up procedure' where rumen liquor was deproteinised and sugars removed, yielding a clean sample with only fermentation products present for analysis (Siegfried *et al*., 1984). A Walters 717 auto-sampler equipped with a RI Detector and a Biorad Aminex HPX 87H column was used in this method.

4.2.6.2 Dacron bag study

The NDF content was measured using the residue from the Dacron bags. The contents of the bags at each time interval were pooled per period for each cow. Samples were then analysed according to the NDF procedure mentioned in section 3.2.5.1.

4.2.6.3 Statistical analysis

A cross-over design with two treatments (low fibre and high fibre) was implemented for the rumen study and analysed using the GLM model (Statistical Analysis Systems Institute, 2012). The data gathered for rumen VFA, rumen NH_3-N and handheld pH were subjected to a main effects ANOVA. The indwelling pH data was subjected to a repeated measures ANOVA. *In sacco* data was fitted to the non-linear model, $p = a + b\ (1 - e^{-ct})$ (Ørskov and McDonald, 1979), to derive the *a*, *b* and *c* parameters. A Students t test was used to confirm the results of the ANOVA and compared the treatment means at a 5 % significance level. Least square means were used to calculate a pooled standard error of treatment means.

4.3 Results and discussion

4.3.1 Rumen pH

Figure 3 illustrates the diurnal pattern of the rumen pH for the low and the high fibre treatments. The highest pH for both treatments was observed at 05h00, *viz.* 6.77 for the low fibre and 6.74 for the high fibre treatment. Concentrates were fed during milking time, which was at 05h30 and 14h00. As seen in figure 3, the pH declined after concentrate intake. The lowest pH reading for the high fibre treatment was 6.09 at 14h30, soon after concentrate feeding, whereas the lowest pH for the low fibre treatment was 6.15 recorded at 20h30. The pattern of rumen pH over time was very similar for the two treatments, although there were differences between treatments at 06h00 and 14h30 where pH in the high fibre treatment was significantly lower than that of the low fibre treatment at both times. According to Bargo *et al*. (2002b), ruminal pH is highest pre-concentrate feeding and lowest post-concentrate feeding which corresponds to the data illustrated in figure 3. The lowest pH for the low fibre treatment was recorded 7h and 30mins after feeding which does not correspond to Nordlund and Garret, 1994; Nocek, 1997; or Cajarville *et al*., 2006 who reported that ruminal pH is lowest 2 – 5 h post-concentrate feeding. According to Owens *et al*. (1996), ruminal acidosis can be defined by pH < 5 and subacute ruminal acidosis by pH < 5.6. Based on the minimum values recorded in figure 3 and Table 8, none of the cows receiving either the low or the high fibre treatment suffered from acute or sub-acute ruminal acidosis. The fact that the pH values in both treatments never went below 6.1 is an indication of a healthy rumen where pH values were maintained at an optimal level. Although the reason for lower pH values for the high fibre treatment shortly after feeding is not readily apparent, it is probably of no biological importance as the differences were quite small and the values were in a pH range that is conducive to normal rumen function.

The extent of pH fluctuations was similar on both treatments and the pH decreased steadily in two cyclic pH drops in the ruminal pH profile. This represents a normal diurnal pH fluctuation in cows being fed concentrates on a pasture based system. Dixon and Stockdale (1999) stated that the decline in pH observed post-concentrate feeding is a result of the presence of readily fermentable carbohydrates (RFC) in the concentrates.

Table 8 shows the handheld pH readings taken at 04h00, 12h00 and 20h00 for the low and high fibre treatment. There were no differences in pH between the low and the high fibre treatment at any of the times. This corresponds to the results from the indwelling pH logging system at the same times. The pH values at 04h00, 12h00 and 20h00 are different between the indwelling logger system and the handheld readings. The handheld readings were taken in rumen fluid that was collected for ruminal VFA and NH_3-N analysis which were exposed to air while the readings were taken. When extracting rumen fluid for VFA and NH_3-N analysis, the rumen fluid that is removed could be from a different region in the rumen than where the indwelling logger system was recording. This was probably the main reason for differences between the measuring methods as it has been reported that pH varies considerably at different locations in the rumen as well as during the day (Colman *et al*., 2010).

According to the results illustrated in Figure 3, ruminal fibre digestion was optimal for both the low and the high fibre treatments throughout the day. Optimal ruminal fibre digestion occurs in the pH range of 6.0 to 6.9 (Pitt *et al.*, 1996; Kolver *et al.*, 1998). When ruminal pH falls in the range of 5.8 to 6.2 for a short duration, a moderate and brief reduction in ruminal fibre digestion may occur (Hoover, 1986). According to Mould *et al*. (1984), complete cessation of ruminal fibre digestion occurs at a pH below 5.0. This being said, the handheld pH readings were > 6.0 at 04h00; between 5.8 and 6.2 at 12h00 and below 5.8 at 20h00 for both treatments. The handheld readings indicate that fibre digestion should be optimal at 04h00 and reduced fibre digestion may occur at 12h00 and 20h00.

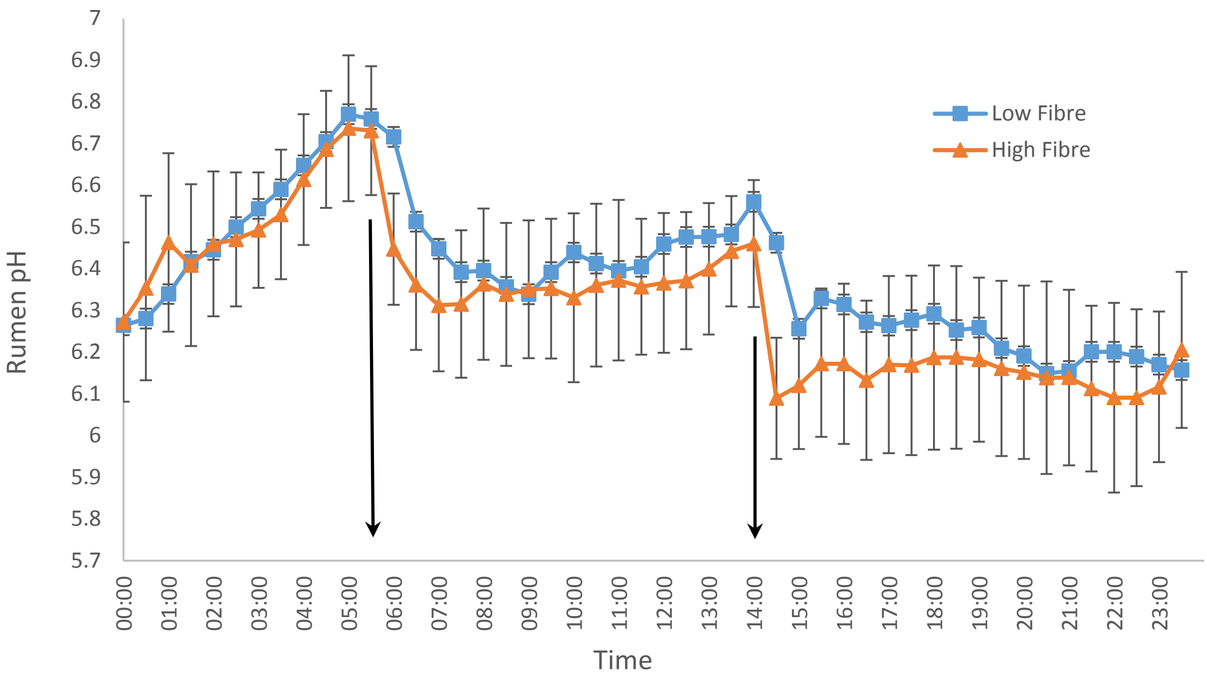

Figure 3 Mean diurnal ruminal pH profile of Jersey cows (n=6) on kikuyu pasture during summer that were fed 6 kg/day (as is) of a high or low fibre concentrate. Arrows indicate when the concentrate was fed. Error bars indicate SEM.

Table 8 The mean handheld pH readings in rumen fluid collected at three time intervals from Jersey cows (n = 6) fed 6 kg (as is) concentrate per day on either the low or high fibre treatment grazing kikuyu pasture

	Treatment			
Time	Low Fibre	High Fibre	SEM[1]	p-value
04:00	6.27	6.30	0.06	0.63
12:00	5.94	5.99	0.06	0.57
20:00	5.69	5.64	0.04	0.40

[1]SEM – Standard error of the mean

4.3.2 Volatile fatty acids

Rumen fluid was collected at 04h00, 12h00 and 20h00 for VFA analysis. The molar proportions of the VFA's in the rumen fluid of cows that received the low and the high fibre treatments is presented in Table 9.

There were no differences between treatments in total VFA, acetic acid, propionic acid, iso-butyric acid and valeric acid concentrations at any of the three time intervals. Acetate, as well as the acetate to propionate ratio, is correlated to milk fat content. No significant differences were found in the milk fat content in this study either. The butyric acid concentration was lower in the high fibre treatment at 12h00 ($P < 0.05$) which corresponds with the data from Lingnau (2011). According to Church (1983) and Lingnau (2011), lowering the starch content in a concentrate results in a decrease in butyric acid. These findings do not correspond with those by Sayers *et al*. (2003), where high fibre supplements had a higher molar proportion of butyrate. Butyrate makes up a small % of the total VFA profile, only about 9-14 % (Church, 1983), as such changes are small and of less importance than changes in acetate or propionate concentration. The iso-valeric acid was lower in the high fibre treatment at 20h00 ($P < 0.05$).

Table 9 Volatile fatty acid (VFA) concentrations in rumen fluid collected at three time intervals from Jersey cows (n = 6) fed 6 kg (as is) concentrate per day on either the low or high fibre treatment grazing kikuyu pasture

		Treatment			
Parameter	Time	Low Fibre	High Fibre	SEM[1]	p-value
Total VFA (mM/L)	04:00	145.0	146.0	6.26	0.60
	12:00	150.6	140.3	4.26	0.15
	20:00	167.8	160.9	5.88	0.45
Acetic acid (mM/L)	04:00	101.9	100.0	4.60	0.73
	12:00	101.6	94.62	2.90	0.13
	20:00	110.8	107.4	4.43	0.60
Propionic acid (mM/L)	04:00	24.6	24.5	1.02	0.97
	12:00	26.0	25.6	1.46	0.78
	20:00	30.6	30.5	1.09	0.93
Acetate : Propionate	04:00	4.16	4.12	0.17	0.88
	12:00	3.92	3.76	0.16	0.29
	20:00	3.64	3.54	0.14	0.58
Butyric acid (mM/L)	04:00	16.09	14.56	0.79	0.16
	12:00	16.64[a]	14.14[b]	0.56	0.03
	20:00	18.72	16.48	0.92	0.10
Iso-butyric (mM/L)	04:00	4.24	3.95	0.33	0.55
	12:00	3.81	3.57	0.22	0.40
	20:00	4.18	3.63	0.39	0.27
Valeric acid (Mm/L)	04:00	1.56	1.51	0.14	0.64
	12:00	1.36	1.37	0.05	0.78
	20:00	1.80	1.64	0.15	0.35
Iso-valeric acid (mM/L)	04:00	1.60	1.41	0.16	0.16
	12:00	1.21	1.00	0.10	0.06
	20:00	1.66[a]	1.28[b]	0.14	0.02

[1]SEM – Standard error of the mean
[a,b] means in the same row with different superscripts differ ($P < 0.05$)

4.3.3 Rumen ammonia-nitrogen

The rumen NH_3-N concentration taken from rumen fluid collected at three time intervals from cows supplemented with low and high fibre treatments is shown in Table 10. There were no differences in rumen NH_3-N concentration between treatments for all three time intervals. According to Satter and Slyter (1974), maximum microbial synthesis takes place above 5 mg NH_3-N/dL and improved microbial synthesis, digestibility and feed intake is within the range of 8.5 to 30 mg/dL (McDonald *et al.*, 2002). The NH_3-N concentration for both treatments fall well within these parameters. 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. According to Satter and Slyter (1974), Hoover (1986) and Khalili and Sairanen (2000) the lowest level of NH_3-N required for rumen micro-organisms to function is between 1 - 6 mg/dL. Satter and Slyter (1974) also state that extreme high NH_3-N concentrations, up to 80 mg/dL, will not inhibit rumen micro-organism activity. The concentration recorded also corresponds to values obtained by Bargo *et al.* (2002a) and Lingnau (2011) and is indicative of efficient utilization of N from pasture (Kolver, 2003).

Bargo *et al*. (2002a) described a trend of NH_3-N to increase after morning milking and again after afternoon milking in response to pasture intake. The NH_3-N concentration increases at each time interval in this study. Bargo *et al.* (2002a) also states that the lowest NH_3-N levels are reached before the morning milking session in response to lower pasture intake.

Table 10 Mean rumen ammonia nitrogen (NH_3-N) (mg/dL) concentrations in rumen fluid collected at three time intervals from Jersey cows (n = 6) fed 6 kg (as is) concentrate per day on either the low or high fibre treatment grazing kikuyu pasture

	Treatment			
Time	Low Fibre	High Fibre	SEM[1]	p-value
04:00	21.76	21.38	0.65	0.40
12:00	21.88	21.64	0.60	0.71
20:00	25.60	26.28	0.48	0.38

[1]SEM – Standard error of the mean

4.3.4 *In sacco* DM and NDF degradability

The degradability parameters for both DM and NDF are shown in Table 11. Data were fitted to the following model (Ørskov and McDonald, 1979) to obtain the first derivative non-linear parameter a, b and c: $P = a + b\,(1 - e^{-tc})$. The proportion of DM that disappeared at time t (hours) is represented by P. The rapidly soluble fraction is represented by a, the potential degradable fraction b and c is the rate at which b was degraded (Ørskov and McDonald, 1979; McDonald, 1981). In this study, neither a, b or c differed significantly between treatments for either DM or NDF of kikuyu pasture. The rapidly soluble component (a) for the DM fraction showed a tendency to differ (P = 0.08), but the small difference between the values are probably of no biological significance. Sayers *et al*. (2003), demonstrated that supplementation type had no effect on DM or NDF degradability of ryegrass pasture. Khalili and Sairanen (2000) found similar results to those of the current study in that *a, b*, and *c* for hay incubated in the rumen was not affected by treatment.

Table 11 Rumen degradability coefficients of kikuyu pasture *in sacco* of cannulated Jersey cows grazing kikuyu pasture fed 6 kg (as is) of low or high fibre concentrates (n = 6)

	Treatment			
Parameter	Low fibre	High fibre	SEM[2]	p-value
DM fraction				
a[1]	18.8	17.9	0.418	0.08
b[1]	73.7	69.0	3.39	0.35
c[1]	0.015	0.018	0.001	0.23
NDF fraction				
a[1]	5.17	4.14	0.831	0.42
b[1]	81.6	78.2	3.23	0.48
c[1]	0.019	0.022	0.002	0.22

[1]Constants determined from $p = a + b\,(1 - e^{-tc})$; *a* = Rapidly soluble fraction; *b* = Potential degradable fraction; *c* = Rate at which *b* is degraded in the rumen (Ørskov and McDonald, 1979)
[2] SEM – Standard error of the mean

Figure 4 and Figure 5 illustrate the actual DM disappearance and the NDF disappearance of kikuyu placed *in sacco* into 6 rumen-cannulated Jersey cows. The zero hour DM disappearance was 18.3% which is an indication of the level of sugars in the pasture. There was no difference between the two treatments for DM disappearance or NDF disappearance at any of the removal times.

The similarities in the DM disappearance and the NDF disappearance could be explained by the similarities in the rumen pH between treatments. Decreasing the amount of readily fermentable carbohydrates, such as starch, from the diet could reduce the rapid formation of VFA and lactic acid in the rumen thereby favouring a fibre digesting environment in the rumen (Meijs, 1986). The findings in this study can be supported by Lingnau (2011), where the low fibre treatment did not result in a significantly lower rumen pH level compared to the high fibre treatment and there were no differences in DM or NDF disappearance between treatments. Extreme daily variations in ruminal pH can be more harmful to rumen microbes than a constant low pH as a result of the constant metabolic readjustments needed by rumen microorganisms (Mertens, 1979). Calsamiglia *et al*. (2002) showed that in a continuous culture with continuous feeding, decreases in fibre digestion were small or insignificant at relatively low pH values (constant at 5.7).

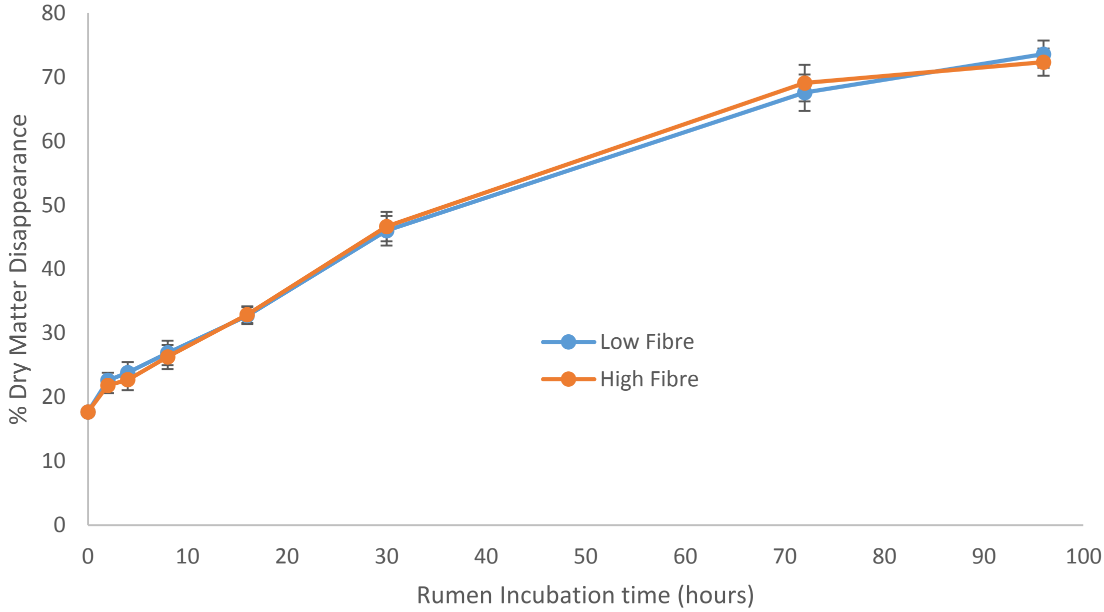

Figure 4 *In sacco* dry matter disappearance of kikuyu placed in the rumen of six cannulated Jersey cows grazing kikuyu pasture and fed 6 kg (as-is) of low or high fibre concentrates

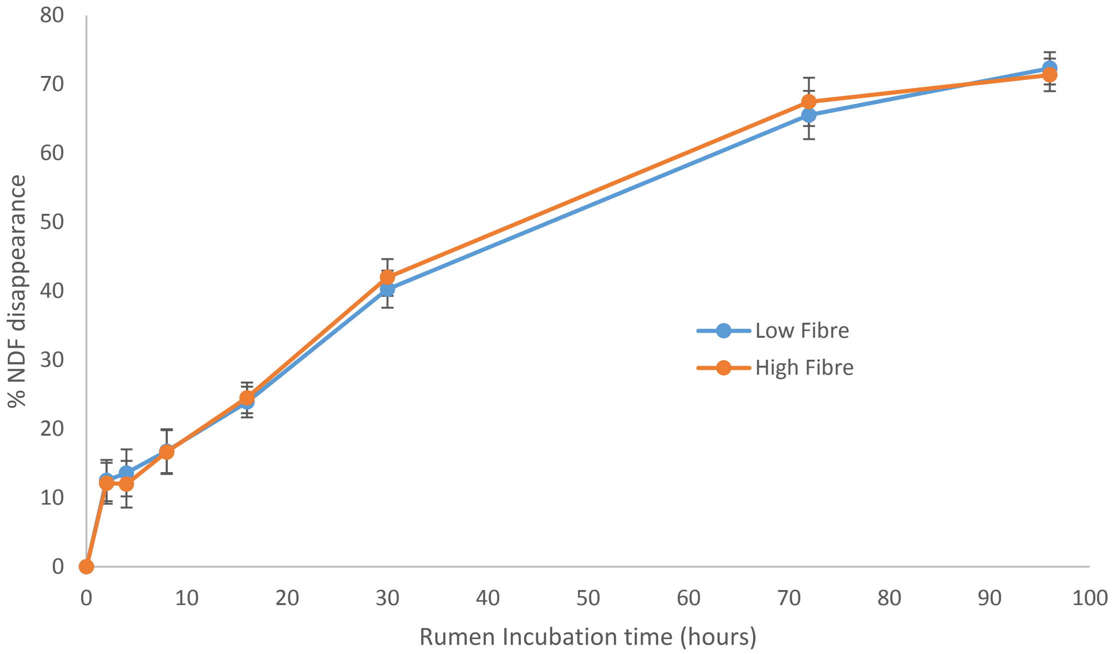

Figure 5 *In sacco* neutral detergent fibre (NDF) disappearance of kikuyu placed in the rumen of six cannulated Jersey cows grazing kikuyu pasture and fed 6 kg (as is) of low or high fibre concentrates

4.3.6 Mean composition of rumen digesta

The mean VFA concentrations of the three collection times, proportions of VFA's, rumen NH_3-N and handheld pH readings are shown in Table 12. The mean iso-valeric acid concentration was lower in the low fibre treatment ($P < 0.05$). Except for butyric acid, there were no differences between treatments in the mean concentration of any of the other VFA's. The molar % of both the butyric acid and the iso-valeric acid were lower in the high fibre treatment ($P < 0.05$). This was explained in section 4.3.2. There were no differences between treatments for the mean pH and rumen NH_3-N. The mean NH_3-N in Table 12 was slightly higher than 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 on pasture based systems. A drop in rumen pH was experienced after the morning milking and again after the afternoon milking session resulting in reduced rumen micro-organism activity and lowering the ability to utilise NH_3-N for microbial protein synthesis.

Figure 6 illustrates the relationship between the VFA concentration, rumen NH_3-N and rumen pH at 04h00, 12h00 and 20h00. As the rumen pH declines over time, the VFA and rumen NH_3-N tends to increase. The maximum NH_3-N concentration occurs at the minimum ruminal pH (Cajarville, *et al*., 2006). The drop in pH corresponds to an increase in NH_3-N concentration, micro-organisms are unable to utilise NH_3-N for microbial protein synthesis.

Table 12 Mean volatile fatty acid (VFA) concentrations (mM/L), proportions of VFA, rumen ammonia nitrogen (NH_3-N) (mg/dL) and handheld pH readings in rumen fluid from Jersey cows (n = 6) grazing kikuyu pasture and fed 6 kg (as is) of either the low or high fibre concentrate.

	Treatment			
Parameter	Low fibre	High fibre	SEM[1]	p-value
Total VFA (mM/L)	156.1	149.0	4.434	0.272
Acetic acid (mM/L)	104.8	100.7	3.317	0.395
Propionic acid (mM/L)	27.02	26.84	1.040	0.852
Butyric acid (mM/L)	17.15	15.06	0.676	0.062
Iso-butyric acid (mM/L)	4.08	3.72	0.130	0.085
Iso-valeric acid (mM/L)	1.23[a]	1.49[b]	0.108	0.009
Valeric acid (mM/L)	1.57	1.51	0.071	0.343
Acetate:Propionate	3.91	3.81	0.143	0.565
Total VFA molar %				
Acetic acid %	67.14	67.61	0.411	0.429
Propionic acid %	17.31	17.97	0.617	0.353
Butyric acid %	10.98[a]	10.09[b]	0.296	0.012
Iso-butyric acid %	2.61	2.50	0.077	0.367
Valeric acid %	1.01	1.01	0.048	0.957
Iso-valeric acid %	0.95[a]	0.82[b]	0.060	0.036
pH	5.96	5.98	0.035	0.837
NH_3N (mg/dL)	23.08	23.10	0.460	0.932

[1] SEM – Standard error of the mean
[a,b] means in the same row with different superscripts differ ($P < 0.05$)

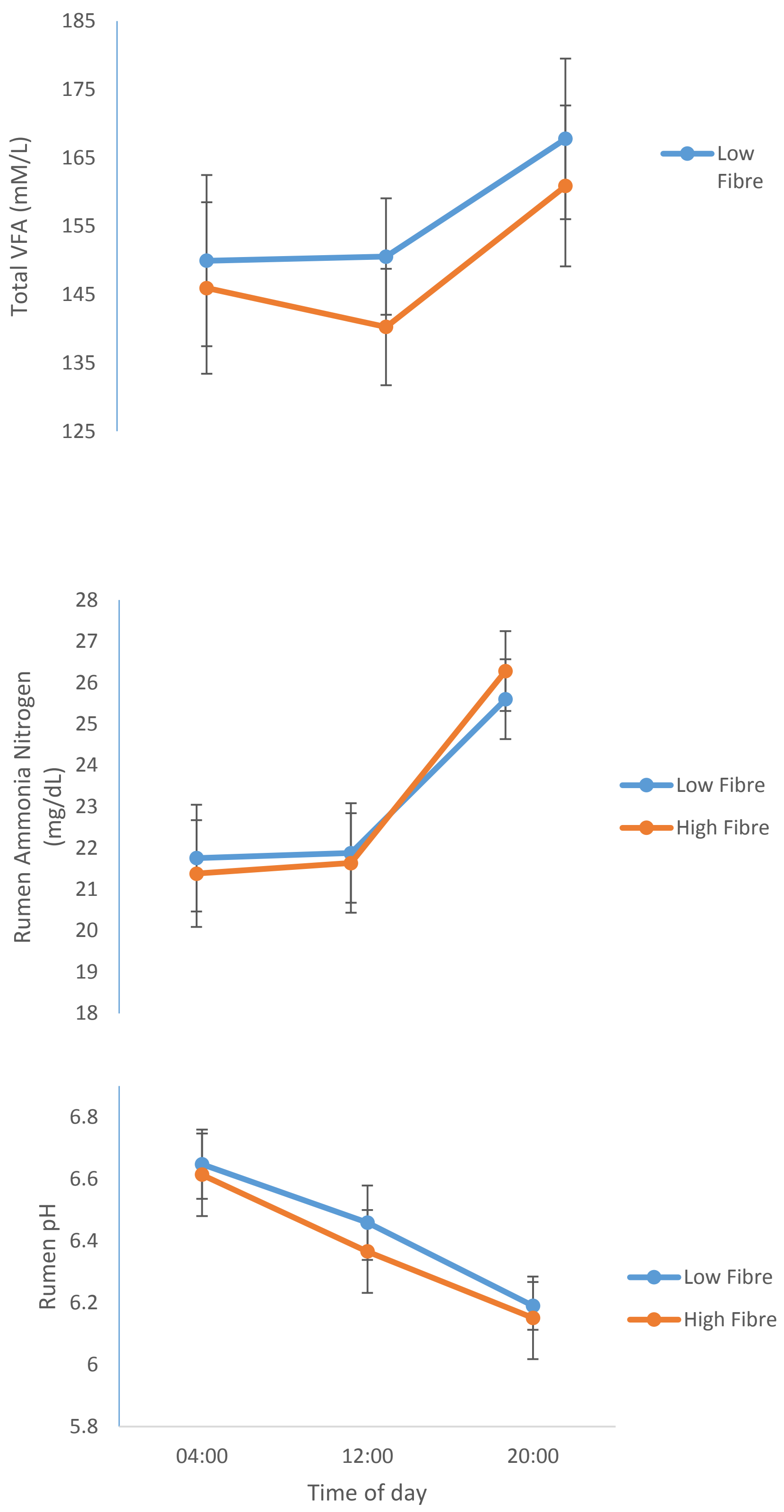

Figure 6 The total volatile fatty acid (VFA) concentration (mM/L), rumen NH_3-N concentration (mg/dL) and rumen pH of six cannulated Jersey cows grazing kikuyu pasture fed 6 kg (as is) of low or high fibre concentrate

4.4 Conclusion

The substitution of maize with high fibre by-products reduces the readily fermentable component of the supplement being fed. The high fibre supplement fed to Jersey cows grazing kikuyu pasture did not affect the ruminal VFA concentrations, NH_3-N concentration, DM or NDF disappearance, or the rumen fluid pH when compared to cows on the low fibre supplement. The butyric acid and iso-valeric acid concentrations were lower in the high fibre treatment ($P < 0.05$). Butyrate and iso-valerate make up a small proportion of the VFA's and are of less importance than acetate and propionate when comparing results to milk yield and the milk components. Furthermore, the actual values of these VFA's and the differences between treatments were small and probably of no biological significance.

No adverse effects were observed in terms of cow health, although the duration of the study was short and no long-term effects can be concluded. The constant monitoring of the rumen parameters indicates a healthy rumen environment for both treatments.

The results from this study suggest that a high fibre supplement would not affect ruminal parameters any differently to a low fibre supplement when fed to Jersey cows grazing kikuyu pasture. A further comparison of the effect of substituting maize with high fibre by-products on the intake of kikuyu pasture could be of interest.

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CHAPTER 5

Economical evaluation

There has been a shift towards producing milk from pasture based systems as opposed to intensive total mixed ration systems. The higher input costs, and lower product prices, are driving producers to place emphasis on efficiency of production per litre rather than production *per se* (McGilloway and Mayne, 1996). Efficiency of production can be increased either by reducing inputs whilst maintaining output, or by increasing both inputs and outputs, such that the value of the additional output exceeds the cost of the extra input. Narrow profit margins and low profitability have attributed to the adoption of low cost, pasture-based systems, managed intensively, to improve profitability and reduce feed costs (Clark and Kannenganti, 1998). However, milk production per cow is frequently lower in pasture-based systems (Muller and Fales, 1998). Proper supplementation strategies are needed to maintain profitable milk production and to minimize the decrease in milk production with intensive grazing.

Innovative grassland management strategies, coupled with supplementation of grazed grass with complimentary concentrates of high nutrient concentration, offers the best hope for resolving this dilemma in low input systems, provided it can be achieved without large-scale substitution of grass (McGilloway and Mayne, 1996).

The calculations represented in Table 13 do not take into account any labour, machinery or any other on farm costs as they are assumed to be the same for all three treatments and will not affect the economic evaluation. It is also assumed that the same amount of pasture was consumed on a daily basis and that there were no differences between treatments as the cows grazed as one herd. The variables taken into account were concentrate price and milk price. The concentrate price (as-is basis) shown in Table 13 was provided by the feed company at the start of the study, January 2013, and is subject to change depending on availability and cost of raw materials, as well as various other factors. The milk price was calculated using the experimental average where there were no significant differences and the treatment average where there were significant differences. The milk price was calculated by the milk buyer in February 2016. The herd size for the calculations consisted of 380 cows, being the average number of cows per producer in the Western Cape. The differences in daily income, concentrate price and profit or loss were expressed relative to the values of the low fibre treatment.

Table 13 Daily margin over feed cost as calculated by milk price according to milk composition, concentrate cost and pasture cost for the low, medium and high fibre treatments

Parameter[1]	Treatment		
	Low Fibre	Medium Fibre	High Fibre
Milk yield (kg/cow/day)	18.5	18.5	18.5
Milk yield (kg/380 cows/day)	7030	7030	7030
Milk fat (%)	4.20	4.20	4.20
Milk Protein (%)	3.66	3.53	3.45
Milk price (R/l)	**R 4.59**	**R 4.49**	**R 4.43**
Milk income (R/cow/day)	R 84.92	R 83.07	R 81.96
Milk income (R/380 cows/day)	R 32269.60	R 31566.60	R 31144.80
Difference in daily income (R/380 cows/day)	R 0.00	R -703.00	R -1124.80
Concentrate price (R/ton)	**R 3910.00**	**R 3530.00**	**R 3160.00**
Concentrate price (R/cow/day)	R 23.46	R 21.18	R 18.96
Concentrate price (R/380 cows/day)	R 8914.80	R 8048.40	R 7204.80
Difference in concentrate price (R/ton)	R 0.00	R -380.00	R -750.00
Pasture cost (10 kg X R1.20 in R/cow/day)	R 12.00	R 12.00	R 12.00
Pasture cost (R/380 cows/day)	R 4560.00	R 4560.00	R 4560.00
Margin over feed cost (R/cow/day)	R 49.46	R 49.89	R 51.00
Margin over feed cost (R/380 cows/day)	R 18794.80	R 18958.20	R 19380.00
Margin over feed cost (R/380 cows/month)	R 563844.00	R 568746.00	R 581400.00
Profit/loss(R/cow/day)	R 0.00	R 0.43	R 1.54
Profit/loss(R/380 cows/day)	R 0.00	R 163.40	R 585.20
Profit/loss (R/380 cows/month)	R 0.00	R 4902.00	R 17556.00

[1]R – South African Rand

The experimental average, 54 cows, was used to calculate the milk production of 380 cows per day. The experimental average for milk fat percentage was used in the calculation of the milk price as there were no significant differences as stated in Chapter 3. The average milk protein concentration from each treatment was used in the calculation of the milk price as it did differ between treatments, see Chapter 3. Due to the difference in protein concentration, the low fibre treatment had the highest milk income per day compared to the medium and high fibre treatment. After considering the difference in concentrate price, the margin over feed cost was highest for the high fibre treatment. Over a period of one month for a herd size of 380 cows, the high fibre treatment showed R17556.00 increase in profit compared to the low fibre treatment.

The R750 difference in concentrate price per ton between the low and the high fibre treatments, leading to a difference of R1710.00 for 380 cows per day, makes the high fibre treatment the most economical option.

The milk price is an important point to consider as the milk buyer will pay on their own specifications whether it be on yield or solids or both. Substituting maize with high fibre by-products can be economically viable although it is subject to change with the maize price and the availability of by-products.

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CHAPTER 6

Critical evaluation

Cows: Sixty cows were selected for the study. Of these, fifty-four cows were selected for the production study and six cannulated cows were selected for the rumen study. The three treatments, namely low, medium and high fibre, was restricted to 17 cows for the production study and 3 cannulated cows for the rumen study due to practical constraints of the milking parlour. A larger number of cows per treatment group with less variation for both the production and rumen study might have provided more accurate data and more significant differences.

Milk recording: The milk yield from each cow was recorded at each milking. During the study the occasional milk recording was missed due to technical problems of some milk meters. These issues were dealt with in order for it not to affect the outcome of the study. More accurate milk recording may have improved the study.

Milk sampling: Milk samples were taken fortnightly. Over the period of the study this equated to four milk samples. Before each milk sampling the sample bottle fittings were washed and opened. The milk sample containers that attach to the milk line were sterilised. The milking times did not have the same time interval between them, which meant that milk samples had to be measured according to the time between milking (1 ml per hour). A sample was taken from each cow, although this proves to be difficult when it comes to handling the samples in the milking parlour. Handling methods could be reviewed to improve milk sampling accuracy.

Pasture: The pasture intake of individual cows on the different treatments was not measured since all cows grazed as one herd. A rising plate meter (RPM) was used to measure pre- and post-grazing heights. It is well known that the RPM is relatively inaccurate when determining pasture yield and intake. The regression equation that was used to determine pasture yield was an average taken from several trials done over several years on the same area of pasture, over different seasons and different grass species. The RPM is a valuable technique for estimating pre- and post-grazing heights to aid in determining stocking rates, as well as grazing and pasture management. For this study, intake was measured on a herd average and it could be beneficial to investigate methods to determine individual pasture intake of cows on different treatments.

Level of supplementation: Each cow received 6 kg (as is) of concentrate per day. The high fibre concentrate had a lower ME value per kg than the low fibre concentrate. The concentrates were formulated on an iso-nitrogenous basis and for practical reasons the concentrates were fed at 6 kg (as is) per cow per day. It could be worth looking at feeding the concentrates at both an iso-nitrogenous and iso-energetic level. Either the level of supplementation could be changed to achieve the same total protein and energy for the total ration of each treatment or possibly keeping supplementation level the same but with additives, such as rumen protected fats, to achieve the same energy levels.

Indwelling pH loggers: Many hours were spent attempting to calibrate these loggers. After calibrating the loggers in the various pH solutions as specified in the guidelines, the loggers were placed in a large plastic bucket with enough tap water to ensure the probes were submerged. The loggers were started before being placed in the bucket, a handheld pH meter (calibrated) was used to record the pH at the start. The loggers were run overnight, approximately 16 hrs, and then stopped in the morning, when another handheld pH reading was taken. Each logger showed a different average reading for the same solution (tap water) over the same period of time after being calibrated according to the same method. These readings were also different to the handheld readings. Each logger was allocated to a cannulated cow at random and was used on that cow for the duration of the study. The cross over design could reduce variation between treatments. A look into alternative methods of recording rumen pH over time would be beneficial to this study.

Rumen sampling and handheld pH readings: Rumen fluid was collected three times during each period where a handheld pH reading was taken for each sample. The sampling times were 8 hours apart. It could be beneficial to take 4 samples at 6 hour intervals as long as a sample is taken at both the highest and the lowest pH times which can be determined from a pH graph over a 24hr interval.

Dacron bag study: Kikuyu grass was cut from the allocated pasture and then dried in order to be cut and placed in dacron bags for the study. The dried kikuyu grass was cut manually with a pair of scissors to try and achieve a uniform size of approximately 5 mm pieces, however the pieces were not uniform. The use of a mill and a sieve with the appropriate pore size would allow for each dacron bag to be filled with grass that has a more uniform particle size and ameliorates the possibility of the smaller particles being digested faster or escaping the bag when placed into the rumen.

APPENDIX A

Table 14 Individual cows blocked according to milk yield, days in milk and lactation number with their randomly allocated treatments

Name	Lactation number	DIM[1]	Milk yield (kg/day)	Block	Treatment[2]
Amsa 54	4	72	25.6	1	1
Susa 81	2	34	24.1	1	2
Amsa 91	3	73	24.0	1	3
Paulet 20	2	58	22.8	2	1
Berta 67	5	60	22.6	2	2
Sally 15	2	51	22.6	2	3
Etna 8	4	80	22.1	3	3
Amsa 67	4	53	21.7	3	1
Mona 6	5	75	21.7	3	2
Paulet 11	5	106	21.7	4	2
Max 32	5	105	21.3	4	1
Max 24	6	95	20.8	4	3
Amsa 116	2	69	20.5	6	1
Amsa 49	5	87	20.4	5	3
Berta 70	5	97	20.3	5	2
Amsa 97	3	25	20.2	7	3
Santa 16	3	71	20.1	5	1
Liz 33	2	58	20.0	6	3
Etna 15	2	54	19.9	6	2
Amsa 96	3	32	19.8	7	2
Berta 89	3	30	19.8	7	1
Berta 102	2	99	19.7	8	1
Amsa 60	5	89	19.6	8	2
Amsa 57	5	89	19.4	8	3
Amsa 68	4	147	19.3	9	2
Sally 7	6	131	19.3	9	1
Lin 32	2	45	19.0	10	3
Liz 29	2	70	19.0	10	1
Tes 10	5	114	19.0	9	3
Lua 10	8	82	18.9	11	1
Susa 47	7	47	18.9	11	3
Liz 24	4	166	18.8	12	1
Esme 3	5	159	18.7	12	3
Susa 74	3	38	18.6	10	2
Etna 12	3	67	18.5	11	2
Lua 20	5	153	18.5	12	2
Paulet 12	4	184	18.5	13	2
Berta 54	5	123	18.3	14	3
Amsa 48	5	189	18.2	13	1
Max 38	3	122	18.2	14	2

Wanda 11	5	154	18.2	13	3
Amsa 90	3	123	17.9	14	1
Amsa 110	3	87	17.6	15	1
Lin 29	3	104	17.6	15	2
Arna 13	5	135	17.5	16	1
Hes 6	5	148	17.5	16	2
Sally 16	2	94	17.5	15	3
Hes 7	3	146	17.3	16	3
Pansy 5	5	84	17.3	17	1
Susa 55	5	45	17.2	17	2
Lass 13	2	51	16.9	17	3

[1]DIM – Days in milk as on the 15th of January 2013
[2]Treatment 1 – Low fibre; Treatment 2 – Medium fibre; Treatment 3 – High fibre