Supplementation of high fibre concentrate to Jersey cows on pasture to overcome winter roughage shortages

by
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Declaration

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Date: December 2012

Abstract

Title:	Supplementation of a high fibre concentrate to Jersey cows on pasture to overcome winter roughage shortages
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Kikuyu over-sown with ryegrass is the most widely used pasture system in the Southern Cape of South Africa. During the winter months the kikuyu component remains dormant and cows are solely dependent on the ryegrass component of the pasture. Ryegrass has a low growth rate (25 - 30 kg DM ha^{-1} day^{-1}) during the winter and early spring months (June - September), resulting in roughage shortages. There are various strategies that can be adopted to overcome these shortages. Most commonly, lucerne hay is bought in. The cost (R 1800 - R 2400 ton^{-1}), however, is high and all farms do not have the capacity to store hay in large quantities. Significant wastages occur when feeding lucerne in ring feeders or feed troughs. Silage made of surplus grass, maize or cereal crops can also be fed. Many farms do not have the implements required for ensiling and due to financial pressure, most farms are at full capacity and as such no surplus pasture is available for ensiling. The purpose of this study was to determine whether a high fibre concentrate supplement and restricted pasture intake strategy could be followed to overcome roughage shortages during the winter months.

Forty eight lactating Jersey cows were blocked according to 4 % fat corrected milk yield (19.1 ± 2.2 kg day^{-1} (±s.d.)), days in milk (104 ± 62.7) and lactation number (4.4 ± 1.8). Cows within blocks were then randomly allocated to one of the three treatments. Treatments were defined according to the amount of a high fibre concentrate supplement that was allocated as well as the level of pasture allocated: Treatment 1 - Low concentrate treatment (LC) received 4 kg concentrate cow^{-1} day^{-1} and 10 kg DM pasture cow^{-1} day^{-1}; Treatment 2 - Medium concentrate treatment (MC) received 7 kg concentrate cow^{-1} day^{-1} and 7 kg DM pasture cow^{-1} day^{-1}; Treatment 3 - High

concentrate treatment (HC) received 10 kg concentrate cow^{-1} day^{-1} and 5 kg DM pasture cow^{-1} day^{-1}. Eight ruminally cannulated Jersey cows were used in the rumen study portion of the trial. These cows were divided into two groups of four and were allocated to the MC and LC treatments. They were used in a cross-over design, where all cows were subjected to both treatments. The metabolisable energy, crude protein and neutral detergent fibre contents of the high fibre concentrate supplement was 10.9 MJ kg^{-1}, 145 g kg^{-1} and 231 g kg^{-1}, respectively. Cows of the three treatments grazed separately, allowing for the restriction of pasture intake according to treatments specifications.

The average daily milk yield and milk fat content of treatments LC, MC and HC was 16.2^{a}, 17.3^{ab} and 18.1^{b} kg day^{-1} ($P < 0.05$) and 4.91^{a}, 4.96^{a} and 4.58^{b} % ($P < 0.05$), respectively. The average stocking rate for treatment LC, MC and HC was 5.07^{a}, 6.07^{b} and 7.64^{c} cows ha^{-1} respectively. Thirty seven percent of pasture was saved on the HC treatment strategy compared to the LC treatment. Cows gained body weight during the study at a rate of 0.62^{a}, 0.28^{b} and 0.27^{b} kg day^{-1} ($P < 0.05$) for the LC, MC and HC treatments, respectively. None of the hourly rumen pH values differed between treatments LC and HC. The rumen pH of cows on treatment LC did, however, spend a longer time below pH 6.0 and pH 5.8 compared to the rumen pH of cows on treatment HC ($P < 0.05$). The digestibility of dry matter and neutral detergent fibre of pasture of cows on treatment LC and treatment HC at 30 hours of incubation was 82.3 and 73.5 % ($P < 0.05$) and 43.5 and 39.2 % ($P < 0.05$), respectively.

The results show that winter roughage shortages can be managed by feeding higher levels of a high fibre concentrate supplement and restricting pasture intake, although a decrease in milk fat content can be expected.

Uittreksel

Titel:	Byvoeding van ’n hoë-vesel kragvoer aan Jerseykoeie op weiding, om winter ruvoertekorte aan te vul
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Kikoejoe, oorgesaai met raaigras, is die mees algemene weidingstelsel in die Suid-Kaap van Suid-Afrika. Tydens die wintermaande is die kikoejoe-komponent dormant en diere is afhanklik van die raaigras-komponent. Raaigras het ‘n lae groeitempo (25 - 30 kg DM ha^{-1} dag^{-1}) gedurende die winter- en vroeë lentemaande (Junie - September) en dit lei tot ruvoertekorte. Daar is verskeie strategieë wat toegepas kan word om die ruvoertekorte te oorkom. Die gewildste is die aankoop van lusern hooi, alhoewel die prys (R 1800 - R 2400 ton^{-1}) die gebruik daarvan beperk. Boere het ook nie altyd die kapasiteit om groot hoeveelhede lusern te stoor nie en baie hooi word vermors as koeie dit uit hooivoerders en voerbakke vreet. Kuilvoer wat gemaak word van surplus weiding, mielies of graangewasse kan ook gebruik word. Baie boere het nie die implemente om kuilvoer te maak nie en as gevolg van finansiële druk, funksioneer die meeste plase reeds op vol kapasiteit en is daar dus nie altyd voldoende surplus ruvoer waarvan kuilvoer gemaak kan word nie. Die doel van hierdie studie was om te bepaal of ‘n hoë-vesel kragvoer en beperkte weiding-inname gebruik kan word om ruvoertekorte gedurende die wintermaande te oorkom.

Agt-en-veertig lakterende Jerseykoeie is geblok volgens 4 % vet-gekorrigeerde melkopbrengs (19.1 ± 2.2 kg dag^{-1}(±s.d.)), dae in melk (104 ± 62.7) en laktasie nommer (4.4 ± 1.8). Koeie binne blokke is vervolgens ewekansig aan een van drie behandelingsgroepe toegeken. Die groepe is gedefinieer volgens die hoeveelheid hoë-vesel kragvoer en weiding wat toegeken is: Behandelingsgroep 1 - Lae-vesel kragvoergroep (LC) het 4 kg kragvoer $koei^{-1}$ dag^{-1} en 10 kg DM weiding $koei^{-1}$ dag^{-1} ontvang; Behandelingsgroep 2 - Medium-vesel kragvoergroep (MC) het 7 kg

kragvoer koei^{-1} dag^{-1} en 7 kg DM weiding koei^{-1} dag^{-1} ontvang; Behandelingsgroep 3 - Hoë-vesel kragvoergroep (HC) het 10 kg kragvoer koei^{-1} dag^{-1} en 5 kg DM weiding koei^{-1} dag^{-1} ontvang. Agt rumen gekanuleerde Jerseykoeie was gebruik in die rumen studie gedeelte van die proef. Die koeie was verdeel in twee groepe wat dan aan die LC en HC behandelings groepe toegeken is in ’n omslag ontwerp met twee behandelings en twee periodes. Die metaboliseerbare energie, ruproteïen en neutraal bestande veselinhoud van die hoë-vesel kragvoer was 10.9 MJ kg^{-1}, 145 g kg^{-1} en 231 g kg^{-1} onderskeidelik. Die drie behandelingsgroepe het apart gewei, sodat weidingtoekenning beperk kon word en weidinginname bepaal kon word.

Die gemiddelde daaglikse melkopbrengs en melk vet % van behandelingsgroepe LC, MC en HC was 16.2^{a}, 17.3^{ab} en 18.1^{b} kg dag^{-1} ($P < 0.05$) en 4.92^{a}, 4.96^{a} en 4.58^{b} % ($P < 0.05$) onderskeidelik. Die gemiddelde veelading van behandelingsgroepe LC, MC en HC was 5.07, 6.07 en 7.64 koeie ha^{-1} onderskeidelik. Volgens die strategie van die HC behandelingsgroep strategie is sewe-en-dertig persent weiding bespaar, in vergelyking met die LC behandelingsgroep. Koeie in behandelingsgroepe LC, MC en HC het in massa toegeneem gedurende die studie teen ‘n tempo van 0.62, 0.28 en 0.27 kg day^{-1} ($P < 0.05$), onderskeidelik. Rumen pH-waardes het nie tussen behandelingsgroepe LC en HC verskil nie. Behandelingsgroep LC se rumen pH was vir ’n langer periode onder pH 6.0 en pH 5.8 as in die geval van behandeling HC. Die verteerbaarheid van droëmateriaal en neutraalbestande vesel van wieding van koeieop behandelingsgroepe LC en HC na 30 ure van inkubasie was 82.3 en 73.5 % ($P < 0.05$) en 43.5 en 39.2 % ($P < 0.05$), onderskeidelik.

Die resultate dui daarop dat winter ruvoertekorte bestuur kan word deur die voeding van hoër vlakke hoë-vesel kragvoer en die beperking van weidinginname, hoewel ‘n afname in melk vet % verwag kan word.

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Abbreviations

AA	Amino acids
ADF	Acid detergent fibre
ADICP	Acid detergent insoluble crude protein
ADL	Acid detergent lignin
BCS	Body condition score
BUN	Blood urea nitrogen
cm	Centimeter
CP	Crude protein
DIM	Days in milk
dL	Deciliter
° C	Degree Celsius
DMI	Dry matter intake
DM	Dry matter
ECM	Energy corrected milk
EE	Ether extract
eNDF	Effective neutral detergent fibre
FCM	Fat corrected milk
G	Gram
GE	Gross energy
ha	Hectare
HF	High fibre
IVDMD	In vitro dry matter digestibility
IVOMD	In vitro organic matter digestibility
kg	Kilogram
LAN	Limestone Ammonium Nitrate
LW	Live weight
ME	Metabolisable energy
MJ	Mega Joules
Mmol	Milli-mol
MUN	Milk urea nitrogen
NDF	Neutral detergent fibre
NDICP	Neutral detergent insoluble crude protein
NE_L	Net energy for lactation

NEFA	Non-esterified fatty acids
NH_3-N	Ammonia nitrogen
NPN	Non protein nitrogen
NSC	Non-structural carbohydrates
NRC	National research counsel
OM	Organic matter
peNDF	Physically effective neutral detergent fibre
PSPS	Penn State Particle Separator
%	Percentage
SCC	Somatic cell count
SD	Standard deviation
SEM	Standard error of the mean
TMR	Total mixed ration
R	South African Rand
RPM	Rising plate meter
RUP	Rumen undegradable protein
VFA	Volatile fatty acids

1 Introduction

Kikuyu over-sown with ryegrass is the most widely used pasture system in the Southern Cape of South Africa. As kikuyu remains dormant during the winter months (June to September), ryegrass is over-sown to fill the fodder flow gap during these months. For this purpose annual ryegrass types are preferred over perennial ryegrass types as the perennial ryegrass only establishes well into the spring and is unable to support intensive grazing during the coldest of the winter months (Dickinson *et al.*, 2004; Van der Colf, 2011). Due to the low temperatures and low light intensities experienced in the Southern Cape region during the winter months the growth of the ryegrass pasture is inhibited and growth rates can be as low as 30 kg DM ha^{-1}, while growth rates can be as high as 70 kg DM ha^{-1} during the summer (Fulkerson & Donaghy, 2001; Dickinson *et al.*, 2004). During the winter months ryegrass pasture is characterised as having a very high nutritive content, low concentration of structural components and a low dry matter (DM), this translates into high crude protein and non-structural carbohydrate (NSC) concentrations and low neutral detergent fibre (NDF) and acid detergent fibre (ADF) concentrations (Meeske *et al.*, 2006; Van der Colf, 2011).

Due to the low growth rate of ryegrass pasture during the winter months the pasture has a longer growth cycle and takes longer to mature, resulting in roughage shortages. Two main feeding strategies have been developed over the years to overcome these roughage shortages, namely feeding additional lucerne hay or some type of silage. Lucerne has to be bought in from outside and the cost is very high (R 1800 - 2400 ton^{-1}). The price of lucerne hay varies widely according to quality and demand, further complicating the financial planning during the already difficult winter months. Smaller farms often do not have the capacity to store a large amount of lucerne hay. Silage can also be bought in for additional feeding but is not always readily available and is also costly. Ideally excess pasture, or a cereal crop, should be ensiled on the farm itself, but many farms do not have the implements or excess roughage available for this. Lucerne hay or silage is then commonly fed using ring feeders and resulting in 10 - 20 % wastage. In addition to the feeding of lucerne hay or silage, cows are put out to graze for half of the day as well as receiving a concentrate supplement in the milking parlour. A concentrate supplement is characterised as having a high concentration of readily fermentable carbohydrates, this is achieved by including high levels of maize and is also the cause of the high price at which such a concentrate supplement is available (Bargo *et al.*, 2003). The return on milk production under these two different feeding strategies (lucerne hay and silage, both with additional concentrates) is minimal and unable to make up for the extra feed costs involved.

It has been shown that it is possible to replace a high starch concentrate supplement that is highly digestible with a low starch and high fibre concentrate supplement, which is less digestible,

without negatively impacting milk production or rumen health (Lingnau, 2011). The lower digestibility of the high fibre concentrate supplement and the high NDF concentration will help to maintain the pH of the rumen, optimising microbial activity. Due to these characteristics of a high fibre concentrate supplement it is possible to feed this concentrate supplement at higher levels at the expense of pasture intake (Bargo *et al.*, 2003). Pasture is the cheapest feed source available and should therefore, be used to its full potential, however the lower pasture availability during the winter months provides a gap in the feeding program. As such the aim of the study was to determine whether feeding a high fibre concentrate supplement at higher levels and restricting pasture allowance would be able to maintain a high level of milk production and rumen health as well as overcoming the winter roughage shortages.

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2 Literature review

2.1 Introduction

The use of cultivated pastures for increased livestock production in South Africa is an idea originally developed in 1812 and was officially investigated for the first time in 1903 (Tainton, 2000). Currently the intensive total mixed ration (TMR) system, which offers narrow profit margins and low profitability, is systematically being replaced by pasture based systems internationally (Khalili & Sairanen, 2000; Delahoy *et al.*, 2003). Pasture based dairy systems are able to produce milk at low costs with a high output per ha of land (Clark & Kanneganti, 1998). Pasture provides the cheapest feed source available to dairy cows and increasing the consumption of pasture will increase the profit margin (Clark & Kanneganti, 1998). Unfortunately, feeding pasture alone is not sufficient to meet the dietary requirements of high producing dairy cows. Energy is the first limiting nutrient on a pasture based system and necessitates the need for supplemental feeding (Kolver & Muller, 1998). Low DMI of cows on a pasture based system also inhibits cows with high genetic merit from producing to their full potential (Jung & Allen, 1995; Kolver, 2003). Ensuring profitable farming on a pasture based system requires the simultaneous management of various factors; appropriate stocking rates, efficient grazing of pasture, maintaining genetic integrity of the herd and supplemental feeding (Kolver, 2003; Macdonald *et al.*, 2008). Milk payment schemes are based on milk composition rather than milk yield, therefore emphasising the importance of ensuring high milk fat and protein content.

2.2 Kikuyu over-sown with ryegrass

2.2.1 General information

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.

Italian ryegrass is an annual ryegrass species, which is most commonly used in the Natal Midlands, Eastern Highveld and Eastern Cape (Dickinson *et al.*, 2004). However Italian ryegrass responds favourably to irrigation and this has increased the areas used to include the Southern Cape region as well (Tainton, 2000). Ryegrass is also referred to as a ‘cool season’ grass species which highlights its partiality to cooler temperatures; optimum growth rates obtained between 15 -

25 °C (Weihing, 1970; Clark & Kanneganti, 1998). It has been determined that solar radiation has a smaller effect on the growth of ryegrass than temperature (Weihing, 1970). Therefore, lower growth rates obtained during winter is due to the colder temperatures and not due to less solar radiation.

2.2.2 Morphology of grasses

As stated by Tainton (2000), pasture production should concern itself with the provision of conditions which favour tiller development, for without tiller development there will be no pasture production. A high tillering rate is extremely important in forage grasses used for grazing, such as ryegrass (Tainton, 2000). Tillering patterns depend on the species of grass but also on the growing conditions; defoliation, high light intensities and low temperatures are all factors which stimulate the rate of tillering (Fulkerson & Donaghy, 2001). When high quality forage is needed, as in grazing systems, grazing must commence before the development of the stem, subsequent growth will then be devoid of any appreciable quantity of stem (Tainton, 2000; Fulkerson & Donaghy, 2001).

2.2.3 Production potential

The maximum growth rate of ryegrass achieved during the autumn and winter months (April - August; 15 kg DM ha^{-1} day^{-1}) is less than half of that achieved during the spring months (September - October; 60 - 70 kg DM ha^{-1} day^{-1}) (Dickinson *et al.*, 2004). This is due to the fact that the production potential of a specific plant is determined by its genetic potential, but reaching the genetic potential depends on environmental conditions (Booysen, 1966). The rate of photosynthesis depends on the leaf size, temperature and the availability of raw materials; carbon dioxide, light and water (Parsons & Chapman, 2000; Fulkerson & Donaghy, 2001). During winter months, low temperatures and low light intensities both result in a lower growth rate and lower production potential of pasture (Weihing, 1970).

Photosynthetic capacity decreases as the plant ages due to the shadowing effect of the increased leaf mass, preventing light from reaching the largest part of the plant (Tainton, 2000). Leaf tillers which are not harvested also eventually die and decay (Tainton, 2000). Therefore, when grazing pasture, care must be taken not to graze pasture too late, negatively impacting the production potential of the pasture.

2.2.4 Establishment of ryegrass

Annual ryegrass should be established during the autumn months, for the Southern Cape region this is March and April (Dickinson *et al.*, 2004). If sown too early ryegrass seedlings will be scorched by the sun and die (Dickinson *et al.*, 2004). Sowing in late March will ensure that pasture is available late June with a drop in production in July - August (Dickinson *et al.*, 2004). Ryegrass

is most commonly an irrigated pasture and the high capital investment of irrigation requires a high output, therefore it is recommended to fertilise before sowing (as per soil test recommendations) and after each camp has been grazed (Botha *et al.*, 2008a).

2.2.5 Why kikuyu over-sown with ryegrass?

In a study by Botha *et al.* (2008a) the grazing capacity and milk production potential of various pastures was estimated. It was found that kikuyu over-sown with ryegrass provided more constant seasonal fodder availability than kikuyu pastures or kikuyu over-sown with white or red clover pastures therefore resulting in less variation in grazing capacity and milk production (Botha *et al.*, 2008a). Kikuyu over - sown with ryegrass was able to provide a more constant fodder flow, even during the winter and early spring months (Botha *et al.*, 2008b). Kikuyu over-sown with clover pastures did however have a higher milk production than kikuyu over-sown with ryegrass pastures, but the lower grazing capacity of kikuyu over-sown with clover pastures limits the use of this pasture system, making kikuyu over-sown with ryegrass preferable (Botha *et al.*, 2008a). The establishment of a kikuyu over-sown with ryegrass system requires fewer and less expensive implements and the establishment of the ryegrass component does not inhibit the summer and autumn production potential of the kikuyu base (Botha *et al.*, 2008a). Annual ryegrass is preferred over perennial ryegrass (Van der Colf, 2011). Annual ryegrass has a faster growth rate than perennial ryegrass and is a hardier plant as it is able to recover faster after being grazed intensively (Dickinson *et al.*, 2004). Annual ryegrass also reaches its highest growth rates during spring whereas perennial ryegrass only reaches its highest growth rate during summer (Van der Colf, 2011).

2.3 Annual Italian ryegrass quality

Table 1 Annual ryegrass pasture quality data from previous studies

Authors	Season[1]	CP (g kg^{-1} DM[2])	ME (MJ kg^{-1} DM)	NDF (g kg^{-1} DM)	ADF (g kg^{-1} DM)
Meeske *et al.* (2006)	Winter	25.1	10.8	45	24.1
	Spring	18	10.9	49	28
Fulkerson *et al.* (2007)	Winter	26.8	10.8	44.1	23.9
	Spring	25.2	10.1	51.3	27
Van der Colf (2011)	Winter	28.5	12.2	39.6	-
	Spring	24.05	11.7	45.4	-

[1] Winter – Months of June, July and August; Spring – Months of September and October
[2] DM – Dry matter

Seasonal effects on pasture nutritive composition can be clearly seen in Table 1. As the season progresses and rainfall becomes sparser the CP and ME of pasture decreases and the structural component of pasture (NDF and ADF) increases (Meeske *et al.*, 2006; Fulkerson *et al.*, 2007; Van der Colf, 2011). The change in pasture nutritive composition must be taken into consideration when formulating a concentrate supplement to be fed to cows on pasture. The low ME value of pasture can also be seen in Table 1, once more highlighting the importance of supplemental feeding as stated by Bargo *et al.* (2003) and Kolver & Muller (1998).

According to Stockdale (1999b) the effect of season on the nutritive composition of pasture is slightly diminished when pasture is under irrigation. Pasture under irrigation is able to better maintain its nutrient composition throughout the changing of seasons and as the pasture matures (Stockdale, 1999).

2.4 Grazing management

Previously grazing management has focused solely on meeting the animal's nutritive requirements and no attention was paid to the effect that certain management practises have on pastures (Fulkerson & Donaghy, 2001). In the past decade the view of grazing management has shifted to managing the interaction between pasture plants and the grazing animals (Fulkerson & Donaghy, 2001). On the other hand ensuring that pastures are grazed efficiently is one of the greatest challenges of a pasture based dairy system. High post-grazing residuals have a larger effect on pasture growth and milk production than low post-grazing residuals (Irvine *et al.*, 2010).

Estimating pasture yield will give an indication of the stocking rate that can be applied to a certain area of pasture and it is the first step to ensuring that pasture is grazed efficiently, but simply estimating pasture yield does not give an indication of the stage of maturity and the effect that grazing will have on the plants. Managing pasture according to plant related indicators associated with re-growth incorporates both plant and animal aspects into grazing management and ensures maximum pasture production and persistence (Parsons & Chapman, 2000; Fulkerson & Donaghy, 2001). Assessing the leaf re-growth stage reflects the stage of recovery of pasture from the previous grazing session as well as the nutritive value of pasture (Fulkerson & Donaghy, 2001). For pasture to resume optimal growth after grazing, it should be grazed without removing the meristematic tissue at the apex (Booysen, 1966). A larger number of active apices will ensure more rapid re-growth. Grazing pasture to a height of 4 - 6 cm or 10 - 12 on the rising plate meter (RPM) will ensure the remainder of sufficient meristematic tissue and the optimal re-growth of pasture (Irvine *et al.*, 2010).

Figure 1 depicts the three leaf pattern of growth which can be used to monitor pasture maturity after grazing (Fulkerson & Donaghy, 2001). The first leaf to emerge begins to senesce as the fourth leaf begins to develop (Fulkerson & Donaghy, 2001). Pasture will also reach its

maximum height once the 3.5 – 4 leave stage commences as this marks the initiation of senescence (Parsons & Chapman, 2000; Fulkerson & Donaghy, 2001).

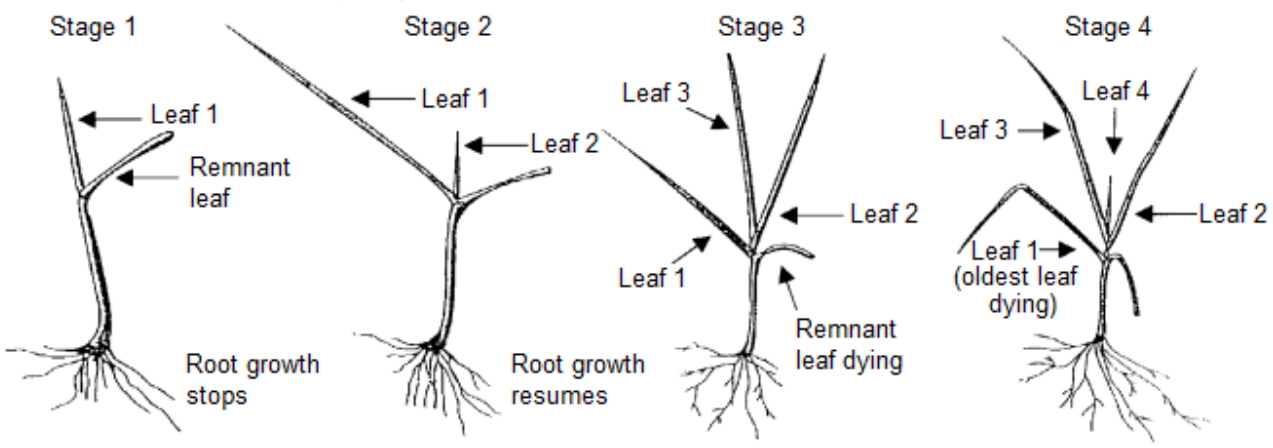

Figure 1 The re-growth pattern of ryegrass tillers after defoliation (Donaghy, 1998)

The growth rate of pasture will determine the production level reached at the 3.5 - 4 leaf stage. Pasture production at the 3.5 - 4 leaf stage could average between 1500 - 1600 kg DM ha^{-1} under stress conditions (low rainfall, extreme cold weather etc.) and even reach production levels as high as 2000 - 2200 kg DM ha^{-1} under conditions of rapid growth (Fulkerson & Donaghy, 2001). This once more emphasises the importance of incorporating both production and plant related factors in deciding when pasture should be grazed.

Strip grazing is the most common grazing program used on kikuyu over-sown with ryegrass pasture. Strip grazing is an adapted form of rotational grazing where animals are allowed access to only a small area of un-grazed pasture, while simultaneously being allowed access to previously grazed pasture as well (Clark & Kanneganti, 1998). Trampling and spoiling of pasture due to urination and defecation are mostly confined to previously grazed pasture, lowering the loss of pasture due to these factors (Tainton, 2000). The kikuyu base, which remains dormant during the winter months, offers protection from trampling to the soil as well as the root system of ryegrass plants. Strip grazing also carries the advantage of ensuring even defoliation of pasture; avoiding unnecessary wastage (Tainton, 2000).

As the season progresses and the growth rate increases the size of each area allocated to grazing should be decreased, the number of animals grazing a specific area increased or the length of time spent on a specific area increased so as to fully utilise the faster growing pasture (Clark & Kanneganti, 1998). Pasture should be grazed on a priority basis, according to the maturity of pasture. In such a scenario excess pasture could be ensiled. If silage was not needed it would be possible to increase the herd size so as to utilise the farm completely for grazing only.

2.5 Determining pasture intake

Determining pasture yield before and after grazing and therefore determining pasture intake, forms an integral part of many production studies and is a useful tool for fodder flow planning as well as applying the most efficient stocking rate (Earle & McGowan, 1979; Gabriëls & van den Berg, 1993; Sanderson *et al.*, 2001). There are a number of methods available to determine pasture intake; these include internal and external markers, faeces collection and digestibility studies, but these methods are expensive and time consuming and do not provide an estimation of pasture yield before grazing. Sample cutting, a capacitance meter and visual assessment are all methods which can be applied to estimate pasture yield before grazing. Sample cutting is a time consuming and destructive method and requires continuous recalibration of reference quadrants (Fletcher & Robinson; 1956, Earle & McGowan, 1979; Gabriëls & van den Berg, 1993). The capacitance meter is based on the concept of the di-electrical ratio of a specific pasture and responds to the surface area of the pasture which in turn is dependent on the density of the pasture as well as the DM of the pasture (Fletcher & Robinson, 1956; Sanderson *et al.*, 2001). The capacitance meter is only accurate when calibrated daily and although it offers a non-destructive alternative to measuring pasture yield it is time consuming and inconsistent. Visual assessment is not destructive to pasture and allows for faster estimation over larger areas but is not effective for the determination of pasture yield post-grazing (Haydock & Shaw, 1975; Stockdale, 1984; Clark & Kanneganti, 1998). Furthermore recalibration of reference quadrants is required for every new pasture which is observed and more than one experienced observer is required to ensure accurate estimations (Earle & McGowan, 1979; Haydock & Shaw, 1975).

The RPM applies the concept of a vertical gradient of chemical constituents which exists in pasture. Under strip grazing management, pasture is grazed in successive layers from the top of the canopy downwards (Delagarde *et al.*, 2000). As such the vertical dispersion of chemical constituents is a function of the chemical composition of the selected pasture (Delagarde *et al.*, 2000). Therefore the quality of pasture depends on the pasture height and density; and predicting pasture yield in relation to pasture height will not only give an indication of the total pasture available but also the pasture quality. This forms the bases on which the RPM was originally designed. The RPM, as it is commonly known today, was first designed by Castle (1976) at the Hannah Research Institute in Scotland. From the time it was first designed it has undergone continuous changes and today various models are available, although all RPM's are based on the same basic principles. The Ellinbank pasture meter that was designed by the Dairy Research Institute, Australia is very similar to the original 'simple disc instrument' designed by Castle (1976) and can be used as a representative model, Figure 2.

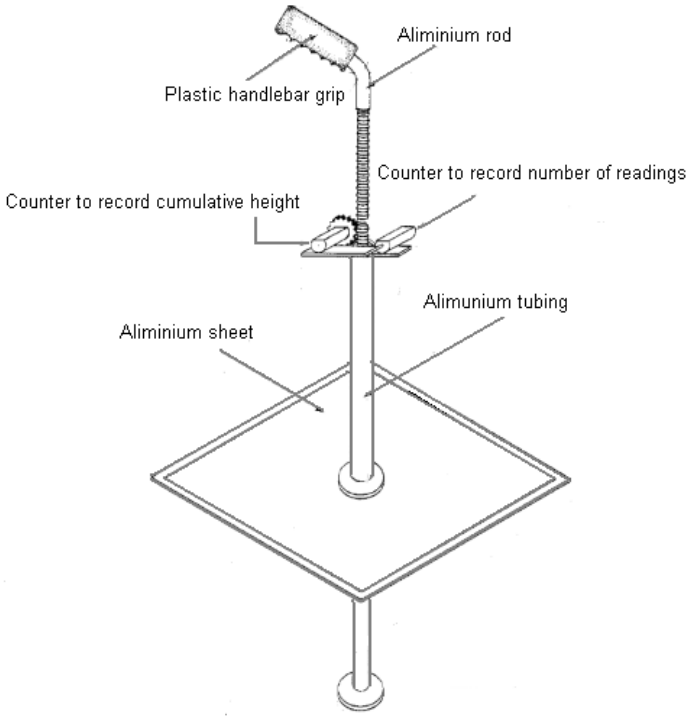

Figure 2 The Ellinbank pasture meter (Earle & McGowan, 1979)

2.5.1 Advantages and disadvantages of the rising plate meter

In a study by Gourley & McGowan (1991), it was found that the RPM is effective in detecting differences between the yields of two pastures exposed to two different experimental treatments. When the RPM was compared to the sample cutting technique it predicted the same pasture yield, even though only 50% of the total area used for the sample cutting method was used for the RPM (Gourley & McGowan, 1991). In a study by Stockdale (1984) it was found that the RPM offers a more accurate method of estimating pasture yield than visual assessment.

Gabriëls & van den Berg (1993) and Sanderson *et al.* (2001) compared the accuracy of the capacitance meter to that of the RPM. In both instances it was found that neither of the methods was precise in estimating pasture yield (Gabriëls & van den Berg, 1993; Sanderson *et al.*, 2001). The acceptable standard error rate for predicting pasture yield is 10 % and in the study performed by Sanderson *et al.* (2001) the RPM had a standard error rate of 26 % and the capacitance meter had a standard error of 33 %. The RPM is more accurate than the capacitance meter, but did not meet the basic standard error requirements (Sanderson *et al.*, 2001). In the study performed by Gabriëls & van den Berg (1993) the use of a RPM yielded a lower coefficient of variation than when a capacitance meter was used, also showing that the RPM is the more accurate method available for predicting pasture yield. Sanderson *et al.* (2001) states that the main reason for the inaccuracy of the RPM is due to the linear regression formulas which were used to convert RPM readings to pasture yield. The formulas used in the study by Sanderson *et al.* (2001) were

calculated on pastures in New Zealand, whereas the study was carried out in America. The same level of inaccuracy was found in a similar study completed in Scotland (Sanderson *et al.*, 2001). This standard error emphasises the importance of using the correct calibration according to season, pasture composition and area.

Overall the RPM proves to be the easiest and least time consuming method to use and is not less accurate than any of the other methods for estimating pasture yield.

2.6 Stocking rate

One of the biggest problems associated with a high stocking rate is the increase in the % of pasture which is affected by urine and faeces as the stocking rate increases (Tainton, 2000). Strip grazing is one of the best methods to follow to avoid unnecessary wastage of pasture. As stocking rates increase, production per animal decreases but production per ha pasture increases (Fike *et al.*, 2003; Tozer *et al.*, 2004; Macdonald *et al.*, 2008). In pasture based dairy systems measuring production per ha is a more appropriate method of determining production (Fike *et al.*, 2003). Increasing stocking rates also improves the efficiency with which pasture is utilised for milk production and it ensures that the pasture remains in a vegetative state and is not lost to senescence and decay (van Houtert & Sykes, 1999), although care must be taken not to increase stocking rate too much so that plant productivity is compromised (Bargo *et al.,* 2002b*;* Fike *et al.*, 2003; Kolver, 2003; Macdonald *et al.*, 2008). High stocking rates could negatively impact the production potential and vigour of pasture in the long term (Tainton, 2000). Although if stocking rates are adapted to the seasons so as to avoid under or over utilisation of pasture the long term effects of high stocking rates will be avoided (Clark & Kanneganti, 1998). The stocking rate of cows on kikuyu pasture over-sown with ryegrass during the winter months (July - August) should only be half that of the stocking rate during spring (September - October) (Dickinson *et al.*, 2004).

2.7 Nutrient requirements of pasture based Jersey cows

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).

2.7.1 Energy requirements

The NRC (2001) refers to the energy required for lactation as net energy for lactation (NE_L) 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 & Muller, 1998).

2.7.2 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 & 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 & 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 & Neil, 1997). The CP of temperate pasture species, such as ryegrass (16 - 18 %) typically exceeds the recommendations of the NRC (2001) (Carruthers & 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 & 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 cows on pasture (Bargo *et al.*, 2003; Sairanen *et al.*, 2005; Fulkerson *et al.*, 2007).

2.7.3 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 & 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 & Griinari, 2003; Kellaway & 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 & 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 & Glimm, 1998). Figure 3 depicts the relationship between rumen health, i.e. ruminal pH, and milk fat content (Allen, 1997). According to Stockdale (1999b) 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.

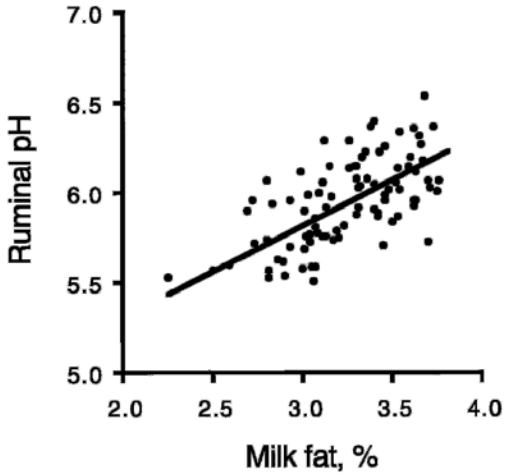

Figure 3 The linear relationship between ruminal pH and milk fat content (Allen, 1997)

2.7.4 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 & 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 & 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 & 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 & 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 & 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 & 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 & 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 & 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).

2.8 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 NE_L requirement of the animal; the minimum level of non-fibrous carbohydrates which can be fed while still maintaining microbial activity and the negative effect that high levels of NDF have on DMI and subsequent production (Jung & 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.

Table 2 Recommended minimum concentrations (% dry matter) of total and forage NDF and maximum concentrations (% dry matter) of NFC (NRC, 2001)

Minimum forage NDF[1]	Minimum dietary NDF	Maximum dietary NFC[2]	Minimum dietary ADF[3]
19	25	44	17
18	27	42	18
17	29	40	9
16	31	38	20
15	33	36	21
14	35	34	22
13	37	32	23

[1] NDF- Neutral detergent fibre
[2] NFC- Non fibrous carbohydrates
[3] ADF- Acid detergent fibre

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 NE_L requirement of the animal and as such the more NFC included the closer the NE_L 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 concentrate feeding do 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 & Neil, 1997).

2.9 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).

2.10 Substitution

As stated by McEvoy *et al.* (2008), substitution rate is the decrease in DMI per kg of concentrate supplement. As such feeding a supplement leads to lower intake of pasture and is referred to as substitution rate (Grainger & 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 & 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^{-1}) = [(Pasture DMI on unsupplemented treatment – Pasture DMI on supplemented treatment) / Supplement DMI].

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 & 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).

2.10.1 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). Generally as the level of concentrate feeding increases the level of pasture allowance will decrease, resulting in an increase in the stocking rate (Faverdin *et al.*, 1991; Vazquez & 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 & Smith, 2000; Bargo *et al.*, 2003; Tozer *et al.*, 2004; McEvoy *et al.*, 2008). Lowering stocking rates results in increased pasture allowance which results in a higher substitution rate (Bargo *et al.*, 2002b).

2.10.2 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 day^{-1} is supplemented there are no negative effects on pasture intake (Kellaway & 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^{-1} (Bargo *et al.*, 2003; Sayers *et al.*, 2003).

It has been found that substitution rate increased by 0.03 - 0.09 kg DM for every kg DM of concentrate supplement consumed (Stockdale, 2000; Kellaway & Harrington, 2004). According to Bargo *et al.* (2003) and Kellaway & 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 & 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 & Harrington, 2004). The decreased rate in fibre digestion lengthens the passage rate of feed, decreasing pasture intake and increasing substitution rate (Kellaway & 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.

2.11 Meeting the nutrient requirements through supplementation

Due to the various nutritional limitations of pasture, supplement feeding should be included as part of a pasture based system. Supplements should be fed to fill the nutritional gap left by pasture and as such it is most important to have an idea of the quality of pasture at a specific time and in a specific area. However this is impractical and costly for individual farmers to investigate so guidelines of the NRC (2001) should be used instead.

Supplementation on pasture is essential to increase the total DMI and energy intake so as to increase milk production, improving the economic viability of a pasture based system (Jung & Allen, 1995; NRC, 2001; Bargo *et al.*, 2003; Delahoy *et al.*, 2003; Sayers *et al.*, 2003; Tozer *et al.*, 2004; Sairanen *et al.*, 2006; McEvoy *et al.*, 2008). By supplementing cows on pasture it is possible to increase the stocking rate and improve the utilisation of land (Bargo *et al.*, 2003; Tozer *et al.*, 2004; Sairanen *et al.*, 2006; McEvoy *et al.*, 2008). The type of supplementation fed to cows will determine the rate of substitution and supplements can be differentiated into concentrate and non-forage fibre based supplements (Bargo *et al.*, 2003).

2.11.1 Concentrate supplements

The response of milk production to concentrate supplementation varies widely, as a result of the substitution effect and various biological factors (Grainger & Mathews, 1989; Bargo *et al.*,

2002b). Generally milk response ranges from 0 – 1.7 L per kg concentrate supplement fed, averaging on 0.5 L per kg concentrate supplement fed (Grainger & Mathews, 1989; Kellaway and Harrington, 2004). Milk response to concentrate supplementation also depends on the level of pasture allowance; limiting pasture allowance and therefore increasing stocking rate, enhances the positive effect of concentrate supplementation (Bargo *et al.*, 2002b). When pasture allowance is not limited it is possible to observe no positive milk response to concentrate supplement feeding (Bargo *et al.*, 2002b). The quality of pasture will also influence the milk response to concentrate feeding. A poor quality pasture (tropical pasture) will show a highly positive response to concentrate supplementation where as a temperate pasture of higher quality will show a smaller response to concentrate supplementation due to the high quality pasture which is already provided.

2.11.2 Non-forage 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) increases milk fat content and milk production and has 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.

2.12 The effects of supplementation on:

2.12.1 Milk yield

The supplementation of cows on pasture will help to bridge the nutritional gap left by the pasture and will as a result improve milk production (Sayers *et al.*, 2003). Kellaway & Porta (1993) and Sairanen *et al.* (2006) found that the increase in milk production per kg of concentrate supplement decreases as the level of concentrate supplement increases, a diminishing returns

curve. This correlation between milk response and supplement level depends on the stage of lactation and genetic merit of the cow and is unpredictable (Bargo *et al.*, 2003; Stockdale, 2000). This correlation highlights the fact that a cow can only produce milk to her full genetic merit and once that level of production is reached, no amount of supplementation will increase production.

The decreased response of milk production to increased levels of concentrate supplementation is also due to the increased passage rate and decreased digestion of NDF (Sairanen *et al.*, 2006). Thus ME intake is less than theoretically estimated or is available in the feed.

2.12.2 Milk composition

Milk composition can be improved by adapting the concentrate feeds fed as supplements to cows on pasture. Milk fat responds readily to dietary manipulation (up to 3 % change) whereas milk protein responds less readily (up to 0.5 - 0.6 % change) (Sutton, 1989; Kennelly & Glimm, 1998; Kellaway & Harrington, 2004). Milk composition also depends on the stage of lactation (Kellaway & Harrington, 2004).

2.12.2.1 Fat content

The changes observed in milk fat content are related to the changes in VFA production in the rumen (Meijs, 1986). Milk fat content depends on the ratio of propionate production to acetate production and this in turn depends on the feed consumed by the animal (Meijs, 1986; Kennelly & Glimm, 1998; Bargo *et al.*, 2003; Sairanen *et al.*, 2006). Concentrate supplement high in starch results in a shift of VFA production to more propionate and results in a depression of milk fat content (Meijs, 1986; Carruthers & Neil, 1997; Bargo *et al.*, 2003). The glucogenic theory as described by Beukelen (1983) explains why an increase in propionate results in milk fat depression; increased levels of propionate in the rumen causes an increase in blood glucose and subsequently, blood insulin levels. Higher levels of insulin stimulate lipogenesis, decreasing the amount of triglycerides available to the mammary gland for milk fat production (Meijs, 1986). Feeding concentrates high in fibre will result in more acetate production in the rumen, increasing milk fat content.

Increasing the level of concentrate supplementation will also cause the pH of the rumen to drop. This drop in pH inhibits the activity of the cellulolytic bacteria and a decrease in acetate production is seen and milk fat content is negatively impacted (Van Soest *et al.*, 1991; Bargo *et al.*, 2002b; Bauman & Griinari, 2003). Feeding a non-forage fibre based concentrate supplement will prevent the sudden decrease in pH, improving microbial activity, as well as providing the rumen micro-organisms with more fibre for acetate production (Sayers *et al.*, 2003).

McMeekan (1956) found that the ability to utilize pasture for milk fat production decreases at higher stocking rates and subsequently lower pasture allowance and as such high stocking rates

could also be linked to low milk fat content.

2.12.2.2 Protein content

Pasture is high in CP but lacks RUP; therefore it is necessary to supply a RUP source such as gluten 20, gluten 60 or fish meal to the concentrate supplement fed to cows (Bargo *et al.*, 2003; Sairanen *et al.*, 2005). Milk protein levels are not highly variable and do not generally respond to protein levels in supplements (Bargo *et al.*, 2003; Sairanen *et al.*, 2006). When high levels of protein were supplemented there was only a 6 - 18 % increase in milk production and milk protein content did not vary (Bargo *et al.*, 2003). According to Kennelly & Glimm (1998), Bargo *et al.* (2002b) and Sayers *et al.* (2003) milk protein levels increase in cows fed a concentrate supplement and decrease in cows fed a non-forage fibre based concentrate supplement. Providing the rumen micro-organisms with a carbohydrate source optimises the synthesis of microbial protein (Bargo *et al.*, 2002b; Sayers *et al.*, 2003; Schwab *et al.*, 2008). This microbial protein provides essential AA which are digested and absorbed in the small intestine, providing the building blocks for milk protein synthesis (Schwab *et al.*, 2008). The negative effect that a concentrate supplement has on the rumen pH and subsequent microbial activity should also be considered.

2.12.2.3 Lactose content

Lactose is the most stable component of milk and the concentration cannot easily be changed through dietary manipulation (Sutton, 1989; Kennelly & Glimm, 1998; Schwab *et al.*, 2008) although it does vary slightly with breed and protein concentrations (NRC, 2001). Lactose is the major osmotic component in milk, as such lactose synthesis in the mammary gland results in an increased secretion of water in the mammary gland leading to an increase in milk production (Kitchen, 1981; Sutton, 1989; Kennelly & Glimm, 1998; Schwab *et al.*, 2008). Lactose concentrations also decrease in response to high somatic cell count (SCC) (Kitchen, 1981). Increase in SCC causes the concentration of NaCl in the mammary gland to increase (Welper & Freeman, 1992). The Na^+ ions increase the osmotic pressure in the mammary gland, which lowers the amount of lactose synthesised (Welper & Freeman, 1992). As such lactose synthesis is lowered, without affecting milk yields (Kitchen, 1981). Propionate produced in the rumen is converted to glucose via gluconeogenesis in the liver; this glucose is then used for lactose synthesis in the mammary gland (Ørskov, 1986; Kennelly & Glimm, 1998; NRC, 2001; McDonald *et al.*, 2002). According to Gibson (1989) and NRC (2001) lactose averages around 4.7 % and 4.85 %, respectively. According to Welper & Freeman (1992) lactose content ranges from 4.61 - 5.04 % across six different dairy breeds.

2.12.2.4 Somatic cell count

Somatic cells found in milk consist of epithelial cells from the udder itself as well as

leukocytes (De Villiers *et al.*, 2000). The concentration of leukocytes increases when udder health is compromised and results in lowered milk production (Kitchen, 1981; De Villiers *et al.*, 2000). Abnormally high SCC levels affect the ability of secretory tissue to synthesis milk and also results in changes in the milk composition (Kitchen, 1981). Overall SCC is influenced by various factors. Somatic cell count is higher at the onset of lactation due to the natural immune system and the production of colostrum as well as at the completion of the lactation cycle when the udder undergoes involution, SCC also increases as the lactation number increases in response to wear and tear on the udder and SCC increases in response to udder irritation and injury as well as depending on the genetics of the cow (Kitchen, 1981; De Villiers *et al.*, 2000). Not all of these factors are relevant under experimental conditions. Cows that are selected to be used in a study are usually required to be in early to mid-lactation, are healthy and average around 3 - 5 lactation cycles. Somatic cell count is a useful management tool for determining the overall udder health of an animal. Somatic cell count has to be below 500 000 cells per mL milk for human consumption although a SCC of more than 300 000 cells per mL milk could be an indication of mastitis and is considered abnormal (De Villiers *et al.*, 2000).

2.12.2.5 Milk urea nitrogen

Protein compounds from feed are hydrolysed to NH_3 by the action of micro-organisms in the rumen (Parker *et al.*, 1995; Bucholtz & Johnson, 2007). Forty to seventy % of this NH_3 is then incorporated into microbial protein, 35 - 65 % is diffused across the rumen wall and 10 % flows directly through to the small intestine with the digesta (Parker et al., 1995; Huntington & Archibeque, 2000). Ammonia absorbed from the gastrointestinal tract is transported to the liver via the hepatic portal vein, where it is converted to urea (Parker et al., 1995; Huntington & Archibeque, 2000; Bucholtz & Johnson, 2007). The urea formed in the liver re-enters the blood and is eventually recycled to the rumen or excreted through urine or milk. As such the concentration of urea in blood is directly proportional to the amount of urea excreted through urine and milk (Jonker *et al.*, 1998).

On a pasture based system the efficiency with which nitrogen from pasture is utilised depends on the concentration of water soluble carbohydrates also present in the pasture as well as on the type of concentrate supplement which is provided to the cows (Carruthers & Neil, 1997; Trevaskis & Fulkerson, 1999; Bargo *et al.*, 2002b). The efficiency with which nitrogen is utilised will determine the extent to which high protein levels affect reproductive performance but will also determine the impact that high levels of nitrogen have on the environment (Jonker *et al.*, 1998; Trevaskis & Fulkerson, 1999). Providing cows on pasture with a concentrate supplement improves microbial activity, subsequently improving nitrogen utilisation and decreasing MUN levels (Carruthers & Neil, 1997; Sairanen *et al.*, 2006). Measuring the MUN levels in milk is the preferred

method for determining the efficiency of nitrogen utilisation over BUN, which is an evasive and time consuming process (De Villiers *et al.*, 2000; Bucholtz & Johnson, 2007).

Providing supplementation to cows on pasture increases the microbial activity of the rumen, allowing for more NH_3 to be utilised by micro-organisms and as a result will lower the MUN values of cows on pasture. MUN values are highly variable depending on stage of lactation, milk yield and change in body weight and as such the recommended MUN values differ (Kohn, 2007). Although the highly accepted recommended value averages around 8 - 12 mg dL^{-1} for samples collected from a bulk tank (Kohn, 2007). Individual MUN values vary widely from 8 - 25 mg dL^{-1} and as such data should be averaged to obtain acceptable values (De Villiers *et al.*, 2000). De Villiers *et al.* (2000) also states that the milk fat content of milk influences the accuracy of MUN concentration; a milk fat content above 4.5 % decreases the reliability with which MUN values can be used. This further emphasises the fact that MUN values should only be used as a guideline and should not be depended on for making major nutritional and management decisions.

2.12.3 Body condition score and live weight

Meijs (1986) found that live weight increases were lower for cows on high fibre supplement than those on concentrate supplement. Bargo *et al.* (2002b) found that grazing cows that received a concentrate supplement mobilised less energy reserves than cows not receiving a concentrate supplement. During early lactation the mobilisation of body reserves will be more extreme to ensure high milk production and a drop in BCS will be experienced (Erasmus *et al.*, 2000). Thus far most research studies pertaining to the effects of supplementation on a pasture based systems on production have spanned only a few months and have used multiparous cows, resulting in insignificant changes in LW. Body condition is more sensitive and is a good indication of whether basal metabolic requirements are being met. Another measure which could provide a valuable indication of the energy status of cows over short term studies is the concentration of non-esterified fatty acids (Bargo *et al.*, 2002b). Unsupplemented cows had a higher plasma concentration of non-esterified fatty acids indicating the mobilisation of body reserves for milk production (Bargo *et al.*, 2002b).

2.12.4 Rumen health and functionality

2.12.4.1 Rumen pH

Concentrate supplements contain a large proportion of readily fermentable carbohydrates (Bargo *et al.*, 2003). These carbohydrates are rapidly fermented which leads to a decrease in rumen pH (Carruthers & Neil, 1997; Bargo *et al.*, 2002b; Bargo *et al.*, 2003; Sayers *et al.*, 2003; Sairanen *et al.*, 2006). There is a negative relationship between the pH of the rumen and the ability of micro-organisms to attach to cell walls of feeds (Hoover, 1986; Shriver *et al.*, 1986). Fibre

digestion is optimised at pH 6.2 (Shriver *et al.*, 1986). As such a decrease in pH below 6.0 leads to a substantial depression in fibre digestion (Hoover, 1986). At pH 5.8 the digestion of NDF decreased to as low as 8.1 % and overall activity of micro-organisms was reduced by 40 % (Hoover, 1986). Growth of certain bacterial species also ceases below pH 6.0 (Hoover, 1986). The severity of low pH values (5.8 - 6.2) depends on the duration of time spent at such a low pH. Cyclic drops in pH which last for a short duration of time are less severe and do not have any long lasting effects on microbial activity (Mould *et al.*, 1983; Hoover, 1986). Calsamiglia *et al.* (2002) determined that the fibrolytic and cellulolytic micro-organisms were able to maintain activity during transitory periods of low pH where as an overall continuous low rumen pH negatively affected activity, lowering the rate of NDF and ADF digestion. A continuously lower pH results in micro-organisms expending more energy on maintenance and less replication will take place and the population size will begin to suffer (Russell & Dombrowski, 1980). When the pH is allowed to rise to an acceptable level the population recovers and activity levels will increase (Russell & Dombrowski, 1980). Calsamiglia *et al.* (2002) found that a drop in pH below 6.0 for less than four hours had negligible effects on rumen activity. This allows for the feeding of concentrate supplements to cows on pasture, where a drop in pH is always experienced in response to feeding.

Managing concentrate supplementation correctly will result in less rapid decrease of pH and more predictable DMI of pasture. Maintaining a more stable rumen pH can be achieved by feeding concentrate supplements in smaller amounts continuously throughout the day, although this is highly impractical (Trevaskis *et al.*, 2004). Another method to maintain rumen pH is feeding non-forage fibre based concentrate supplements which are less rapidly degradable (Sayers *et al.*, 2003).

2.12.4.2 Rumen volatile fatty acids

Acetate, butyrate and propionate are the three major end products of carbohydrate fermentation in the rumen (Kennelly & Glimm 1998; McDonald *et al.*, 2002). Of all VFA produced in the rumen, 80 - 90 % are absorbed directly across the wall of the rumen, reticulum and omasum (McDonald *et al.*, 2002). The remaining VFA are utilised by rumen microorganisms or passed through to the abomasum and small intestine (Kennelly & Glimm, 1998; McDonald, *et al.*, 2002).

Acetate is the main VFA produced in the rumen and is mainly found in peripheral circulation (Ørskov, 1986; McDonald *et al.*, 2002). Acetate concentration is not correlated to milk yield but rather highly positively correlated to milk composition, most notably milk fat content (Kennelly & Glimm, 1998; Seymour *et al.*, 2005).

As butyrate diffuses across the rumen wall it is converted to β-3-hydroxybutyrate (Ørskov, 1986; McDonald *et al.*, 2002). β-3-hydroxybutyrate is a ketone body and can be utilised as an energy source by skeletal and heart muscles (Ørskov, 1986; McDonald *et al.*, 2002). Ketones also

play an important role as an energy source for milk synthesis during early lactation when cows are still in a negative energy balance (Ørskov, 1986; McDonald *et al.*, 2002). Butyrate concentration is highly positively correlated to milk yield as well as DMI although it is not correlated to milk composition (Seymour *et al.*, 2005).

Less than 10 % of the glucose requirements of ruminants are met through the dietary sources of glucose, as glucose from the diet is utilised by the microorganisms themselves (Ørskov, 1986; McDonald *et al.*, 2002). When propionate crosses the rumen wall a portion of it is converted to lactate and the remainder is transported to the liver (Ørskov, 1986; McDonald *et al.*, 2002). Propionate is utilised for the production of glucose via gluconeogenesis in the liver, which is able to provide up to 90 % of the glucogenic needs of the animal (Ørskov, 1986; Kennelly & Glimm, 1998; McDonald *et al.*, 2002). A portion of the propionate bypasses the liver and is found in the peripheral blood supply, this can then be used directly for energy production (McDonald *et al.*, 2002). Propionate is highly positively correlated to milk production but is not correlated to milk composition (Kennelly & Glimm, 1998; Bargo *et al.*, 2002b; Seymour *et al.*, 2005).

Rumen epithelium cells preferentially oxidise VFA in the order butyrate > propionate > acetate (Baldwin & McLeod, 2000). By increasing the concentration of butyrate in the rumen less propionate will be oxidised to lactate by the rumen epithelium cells, resulting in an increase in propionate to the liver (Baldwin & McLeod, 2000; McDonald *et al.*, 2000). Increasing levels of butyrate will also result in less oxidation of acetate and increase this VFA supply to peripheral tissues (Baldwin & McLeod, 2000). The highly positive correlation of butyrate concentration in the rumen to milk yield is explained when the high affinity of rumen epithelial cells for butyrate is taken into account. It is not the higher supply of butyrate which leads to improved milk yield, but rather the lower oxidation rate of propionate to lactate and the subsequent increased supply of propionate to the liver which leads to an increase in milk yield.

The acetate to propionate ratio is highly positively correlated to milk composition, thus an increase in acetate to propionate will result in an increase in milk fat content (Seymour *et al.*, 2005). The relative proportions of VFA can be altered by changing the composition of the diet. More fibrous, mature forage results in a higher concentration of acetate in the rumen and a less fibrous, younger forage results in a higher concentration of propionate (McDonald *et al.*, 2000; Sairanen *et al.*, 2005). The ratio of forage to concentrate supplements in the diet also influences VFA production (Sairanen *et al.*, 2006). By increasing the inclusion level of concentrate supplements in the diet the propionate production increases at the expense of acetate production therefore increasing milk yield but decreasing milk quality (Carruthers & Neil, 1997; Sairanen *et al.*, 2006).

The level of VFA (absolute values and ratios) recorded from rumen samples will therefore give an indication of the overall rumen health but also of the potential for milk production from the

supplied feed.

2.12.4.3 Rumen ammonia nitrogen

Ammonia nitrogen (NH_3-N) levels vary according to pasture quality and supplement type but it also varies throughout the day in response to DMI (Khalili & Sairanen, 2000). The concentration of NH_3-N increases after the consumption of pasture which is high in CP. In a study performed by Bargo *et al.* (2002a) the highest level of NH_3-N concentrations ranged between 20.7 mg dL^{-1} and 25.8 mg dL^{-1} and was recorded during the period of grazing, after cows where milked. The lowest NH_3-N concentrations were observed early in the morning, before the morning milking session and early in the afternoon, before the afternoon milking session and ranged between 14.2 mg dL^{-1} and 17.3 mg dL^{-1} (Bargo *et al.*, 2002a). Khalili & Sairanen (2000) also found that NH_3-N levels peaked in the evenings in response to high grazing activity after evening milking.

In the study by Lingnau (2011) NH_3-N levels increased in response to the consumption of a high starch concentrate. This is due to the rapid degradation of the readily fermentable carbohydrates which resulted in a sharp decrease in pH (Lingnau, 2011). A drop in pH results in a decrease in microbial activity. Micro-organisms are then unable to utilise the NH_3-N in the rumen and the concentration increases. Feeding a non-forage fibre based concentrate supplement lowers the supply of readily fermentable carbohydrates and prevents a sharp decrease in pH, stabilising NH_3 levels, therefore improving overall rumen health (Sayers *et al.*, 2003; Trevaskis *et al.*, 2004).

Lowered NH_3-N levels in response to concentrate supplement feeding could be as a result of substitution of pasture for concentrate supplement, thus lowering the N intake and lowering NH_3-N in the rumen (Berzaghi *et al.*, 1996). When low levels of concentrate supplement are fed or a concentrate supplement high in a non-forage fibre source is fed, micro-organism activity can be improved, improving the utilisation of NH_3-N in the rumen (Berzaghi *et al.*, 1996).

In a study by Meeske *et al.* (2006) the CP of ryegrass pasture was found to decrease from 251 g kg DM^{-1} during winter to 180 g kg DM^{-1} during spring. Decreasing CP levels results in decreasing NH_3-N levels in the rumen. According to Satter & Slyter (1974), Hoover (1986) and Khalili & Sairanen (2000) micro-organisms require a very low concentration of NH_3-N to function optimally; only 1 - 6 mg dL^{-1}. This low requirement for NH_3-N is due to the high affinity of micro-organisms to NH_3-N. As such, lower levels of CP in the pasture should not excessively affect microbial activity in the rumen. Extreme high levels of NH_3-N in the rumen, up to 80 mg dL^{-1} will not inhibit the activity of micro-organisms in the rumen, highlighting the high tolerance of micro-organisms to varying levels of NH_3-N (Satter & Slyter, 1974). According to Mehrez *et al.* (1977) the concentration of ammonia in the rumen which ensures optimal microbial activity is 23.5 mg dL^{-1}. A concentration below this could result in lowered fermentation rates, increasing gut fill and limiting feed intake (Mehrez *et al.*, 1977). The high digestibility of ryegrass pastures during the winter

months reduces the need for such a high concentration of NH_3-N; pasture will be digested sufficiently without the rumen reaching maximum fermentation.

A lot of variation is found in the literature and no optimum NH_3-N concentration can be decided on conclusively.

2.12.4.4 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.

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3 Problem statement

There are various limitations to maintaining profitability during the winter months, most notably the lack of pasture and the decrease in milk production. The lack of pasture requires additional feeding of some form; this, linked to the lower milk production results in huge financial losses. Addressing the main problems identified during the winter months, the aim of the study was to determine whether feeding a high fibre concentrate supplement at higher levels and restricting pasture allowance would be able to maintain a high level of milk production. Rumen health and activity are of utmost importance to ensuring optimum production; as such an investigation of these parameters was also included in the study. The amount of pasture which could be saved was also investigated to allow for practical application of the results by farmers in the area.

4 Materials and methods

4.1 General information

4.1.1 Location and duration of project

The study was carried out at the Outeniqua Research farm near George in the Western Cape of South Africa. The farm is situated at 22º 25' 222" E and 33º 58' 702" S. The mean temperatures experienced during the study were: maximum = 18.85 °C and minimum = 7.92 °C (ARC, 2011). The area received 247 mm rainfall during the study period (ARC, 2011).

The study was conducted from 5 July 2011 to 5 October 2011, spanning over a total of 92 days. Data collection commenced on 28 July, that is to say the adaptation period constituted 23 of the 92 days.

4.1.2 Pasture management

A total area of 8.876 ha was used during the research period. The pasture consisted of kikuyu (*Pennisetum clandestinum*) over-sown with annual Italian ryegrass (*Lolium multiforum*). The kikuyu portion of the pasture remained dormant during the research period (winter and early spring months); therefore only ryegrass was available to cows. The soil of the 8.876 ha area used for the study was characterised by a Katspruit soil form, of the family Lammermoor. Each camp was fertilised with 42 kg N (LAN, limestone ammonium nitrate) ha^{-1} after grazing.

4.1.3 Animal welfare

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

4.2 Production study

4.2.1 Experimental design

Forty eight lactating Jersey cows from the Outeniqua Research farm where used in the production study. A complete randomised block design was used to assign cows to treatments so as to control and reduce experimental error (Kuehl, 2000). Cows were divided into 16 different blocks. Blocks were defined according to DIM, lactation number, milk yield and milk fat content, as such cow with similar DIM, lactation number, milk yield and milk fat content were placed in the same block. Each cow within a block was then randomly allocated (Random number function, Microsoft Excel 2010) to a treatment, resulting in three different groups with similar parameter values, as seen in Table 3. Cows within a treatment were marked with coloured neck tags to avoid incorrect allocation of pasture or concentrate supplement.

Table 3 Mean (± s.d.) DIM, lactation number, milk yield, milk fat content and 4 % FCM of all three high fibre concentrate supplement treatments (n = 16)

Parameter[1]	Treatment[2]		
	LC	MC	HC
DIM	111 ± 62.5	101 ± 57.3	100 ± 70.98
Lactation no.	4.50 ± 1.79	4.38 ± 1.96	4.25 ± 1.81
Milk yield (kg)	14.7 ± 1.93	14.5 ± 2.26	14.9 ± 2.37
Milk fat (%)	5.33 ± 0.46	5.04 ± 0.63	5.24 ± 0.75
4 % FCM (kg)	18.4 ± 1.70	19.6 ± 2.28	19.3 ± 2.56

[1] DIM - Days in milk; FCM- Fat corrected milk
[2] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; MC - Medium concentrate treatment receiving 7 kg (as is) high fibre concentrate supplement and 7 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day

All cows within the production study were fed the same high fibre (HF) concentrate supplement (Table 4); which was formulated and processed by NOVA feeds, George; regardless of treatment. The HF concentrate supplement was fed in a pelleted form. Treatments were defined according to the amount of HF concentrate supplement allocated as well as the level of pasture allocated:

Treatment 1: Each cow in the low concentrate treatment (LC) received 4 kg (as is) per day of the HF concentrate. The concentrate supplement was offered in two portions of 2 kg each during the morning (07:30) and afternoon (14:00) milking sessions. Each cow was also allocated 5 kg DM of pasture after the morning milking session and 5 kg DM of pasture after the afternoon milking session (10 kg DM in total).

Treatment 2: Each cow in the medium concentrate treatment (MC) received 7 kg (as is) per day of the HF concentrate. The concentrate supplement was offered in two portions of 3.5 kg each during the morning (07:30) and afternoon (14:00) milking sessions. Each cow was also allocated 3.5 kg DM of pasture after the morning milking session and 3.5 kg DM of pasture after the afternoon milking session (7 kg DM in total).

Treatment 3: Each cow in the high concentrate treatment (HC) received 10 kg (as is) per day of the HF concentrate. The concentrate supplement was offered in two portions of 5 kg each during the morning (07:30) and afternoon (14:00) milking sessions. Each cow was also allocated 2.5 kg DM of pasture after the morning milking session and 2.5 kg DM of pasture after the afternoon milking session (5 kg DM in total).

Table 4 Ingredient and chemical composition of the high fibre concentrate supplement fed to cows on all three high fibre concentrate supplement treatments

Ingredient	g kg^{-1} (DM^{1})
Finely ground maize	130
Hominy chop	300
Wheat bran	391
Gluten 20	100
Molasses (liquid)	40
Feed lime	22
Salt	6
Acid buff	6
Premix[2]	5
Nutrient	**g kg^{-1} (DM)**
Dry matter	864
Crude protein	134
Rumen undergradable protein (% CP)	381
Metabolisable energy (MJ ME/kg DM)	12.2
Neutral detergent fibre	266
Acid detergent fibre	81.0
Ether extract	60.2
Ash	74.1
Calcium	12.4
Phosphorous	6.94
Magnesium	3.82

[1] DM - Dry matter
[2] Premix - 4 mg kg^{-1} Copper; 10 mg kg^{-1} Manganese; 20 mg kg^{-1} Zinc; 0.34 mg kg^{-1} Iodine; 0.2 mg kg^{-1} Cobalt; 0.06 mg kg^{-1} Selenium; 6 x 10^{6} IU Vitamin A; 1 x 10^{6} IU Vitamin D_3; 8 x 10^{3} IU Vitamin E

4.2.2 Pasture allocation

Cows on the three treatments were grazed separately, allowing for the pasture intake to be monitored and restricted. Pasture was allocated according to the treatment specifications as previously stated in 4.2.1. The total area of 8.876 ha was divided into 24 camps and each camp was divided into two lanes, Figure 4.

Each lane was measured before grazing using the rising plate meter (RPM) method as described by Castle (1976). The linear regression equation: Y = 77.1 * H – 530, where Y = DM

yield and H = RPM reading, was used to estimate the amount of pasture (kg DM) available per lane (Van der Colf, 2011). The total amount of pasture (kg DM) available per lane, the pasture intake allocated to each treatment and the number of cows per treatment was then used to determine the number of breaks in which the specific lane could be divided and grazed. Once the pasture had been measured and the number of grazings calculated, polywire was used to lay out the strips for each grazing.

During the study the 8.876 ha of pasture was grazed three times (i.e. three grazing cycles). Camps were allocated to each treatment during the first cycle. Once both lanes in a camp had been grazed, the treatment was moved to the next available camp. Therefore, camps were not assigned to treatments beforehand; instead the pasture yield available per camp (during the first cycle) and the pasture allocated to each treatment determined the total number of camps assigned to a specific treatment. During the second and third cycles, once a specific camp had been grazed, cows were moved to the next camp which had previously been assigned to their specific treatment. The allocation of treatments to specific camps during the first cycle can be seen in Figure 4. Each camp was clearly marked with a colour tag to ensure that the correct treatment was always put onto the correct camp and fresh water was available at all times.

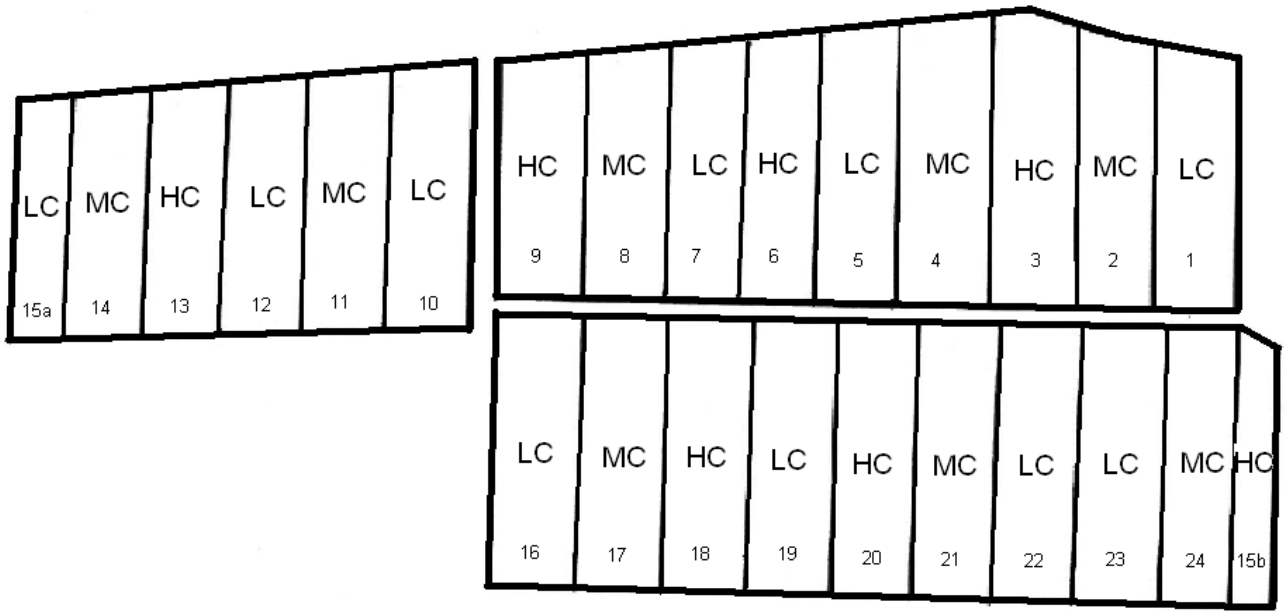

Figure 4 Layout of the area used for the study showing which camps were assigned to the low concentrate treatment (LC), medium concentrate treatment (MC) and the high concentrate treatment (HC). LC - Low concentrate treatment (4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day); MC - Medium concentrate treatment (7 kg (as is) high fibre concentrate supplement and 7 kg DM pasture per day); HC - High concentrate treatment (10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day)

Once a lane of a camp had been grazed and the treatment had been moved to the next lane the pasture yield was again measured using the RPM. During the adaptation period the reading obtained from the RPM was used to determine how well the pasture had been utilized and how accurately the regression equation Y = 77.1 * H – 530, where Y = DM yield and H = RPM reading, was able to allocate pasture. A reading between 10 and 12 is indicative of a pasture which had been utilized well; not too much pasture was wasted, neither was the pasture over grazed.

Throughout the duration of the study segments of the pasture was measured using the RPM, cut using a ring at 3 cm height, weighed and dried for the development of a linear regression equation (5.3) specific to the time period during which the pasture was grazed. The regression obtained was used to estimate pasture intake of each treatment, with the RPM values measured before and after grazing.

4.2.3 Feeding and milking program

Cows were milked twice a day at 07:30 and 14:00. Once cows had been brought up from the pasture they were separated into their respective treatments. During the milking process cows were fed the HF concentrate supplement by hand, which had been weighed out accurately into individual plastic bags according to the treatment specifications (4.2.1). After milking, cows were led back to the pasture where they were separated into treatments once more and placed into their respective camps.

4.2.4 Data collection

4.2.4.1 High fibre concentrate supplement and pasture samples

During the study period, grab samples of the HF concentrate supplement were taken three times a week over eight weeks and pooled per two week period, resulting in four samples for analyses. Samples were thoroughly mixed and dried at 60 °C for 72 hours for preservation and for the determination of the DM content. Representative grab samples were then taken from each dried, pooled sample and ground through a SCW Hammer mill fitted with a 1 mm sieve. Samples were stored in clearly marked, airtight plastic containers for further analyses.

Pasture samples were collected over eight weeks within the production study period for all three treatments, resulting in 12 samples for analyses. Samples were cut once a week for each treatment. A metal ring with a height of 3 cm and area of 0.098 m^2 was placed randomly on the pasture being sampled. All plant material within the area of the ring was cut 3 cm above the ground. Two samples were cut per treatment. All samples were weighed and dried at 60 °C for 72 hours so as to determine the DM content and to preserve the sample for further analysis. Each of the samples was then ground through a SCW Hammer mill fitted with a 1 mm sieve. Milled samples were pooled per treatment, over two weeks. Samples were stored in clearly marked,

airtight plastic containers for further analyses.

Chemical analyses were performed on each of the HF concentrate supplement and pasture samples to determine DM, ash, CP, NDF, ADF, ADL, NDICP, ADICP, EE, IVOMD, starch. The methods followed during the analyses are discussed in 4.4.

4.2.4.2 Milk yield and milk samples

Milk yields for each individual cow were recorded electronically twice a day by means of the Dairy Master Computer software program and a 20 point swing over milking machine for the total duration of the study. 4 % FCM yield was calculated using the Gaines formula (Gaines, 1928) where 4 % FCM = (0.4 * kg milk) + (15 * kg fat). This formula allows for the correction of milk yield to a constant energy basis (Gaines, 1928; NRC, 2001).

Milk samples were collected six times over the study period for each individual cow. The Dairy Master milking machine siphoned off approximately 200 ml of milk, to a sampling container, over the length of the milking session. The milk in the sampling container was then gently mixed to ensure that no milk fat was allowed to settle out. A specific volume, depending on the milking session, of the sample was then measured out from this container into a pre-labelled milk sample bottle. Samples were taken during the morning and afternoon milking session and pooled for the day so as to allow for any variation of milk fat between the morning and afternoon milking sessions. Only six hours separated the morning and afternoon milking sessions and 18 hours separated the afternoon and morning milking sessions, therefore milk was sampled in the ratio of 18 ml from the morning milking session and 6 ml from the afternoon milking session. The pre-labelled milk sample bottles each contained a potassium dichromate ($K_2 Cr_2 O_3$) pellet as preservative.

4.2.4.3 Live weight and body condition score

All cows were weighed the day before the commencement of the study, as well as on the first day of the study. Weighing was performed after the morning milking session. The mean of the weights over two days was used to reduce variation that could arise from variations in pasture intake, urination and defaecation. The same process was followed during the last two days of the study.

The BCS of all cows was performed simultaneously with the weighing of the cows, on the first and last day of the production study. The BCS was performed using the five point scale described by Wildman *et al.* (1982) and Edmonson *et al.* (1989), where a score of one indicates an extremely thin cow and a score of five indicates an extremely fat cow.

4.3 Rumen study

4.3.1 Experimental design

Eight ruminally cannulated cows were used in the rumen study. Four of the cannulated cows were then randomly allocated to either the LC or HC treatment at the onset of the study, bringing the total number of cows on each of the two treatments (LC and HC) to 20. Four extra cows were included into treatment MC for practical purposes such as the 20 point milking system and allocation of pasture. The eight cannulated cows and four extra cows were milked, grazed and fed alongside the other cows on the treatment and the same procedures as described in 4.2 was applied to them. The collection of samples and data from the cannulated cows was carried out over two periods. The first period was conducted from 28 July 2011 to 4 August 2011. After the first period the cannulated cows were rotated between treatment LC and HC and allowed to adapt. The extra cows on treatment MC remained for the duration of the rumen study. The second period was conducted from 15 August 2011 to 20 August 2011.

After the conclusion of the second period, all eight cannulated cows were removed from treatment LC and HC and the four extra cows were removed from treatment MC. Milk yield and milk quality data obtained for the cannulated cows and the extra cows were not included in the production study.

4.3.2 Data collection

4.3.2.1 Rumen pH profiles

TruTrack pH Data Loggers (Model pH-HR mark 4, Intech Instruments LTD, New Zealand) were used to allow for the continuous recording of rumen pH during each of the rumen study periods. The pH data loggers used were embedded into cannula plugs as described by Lingnau (2011). The pH data loggers were calibrated with various buffer solutions (pH 4 and 9) before insertion into the rumen. The Omnilog Data Management Program, Version 1.64 was used for the calibration as well as the downloading of recorded data. On the morning of insertion loggers were activated or ‘turned on’.

Upon insertion of the loggers, cows were once again secured in the crush. The cannula plug was removed and replaced by a cannula plug with an embedded logger. Loggers remained in the rumen, recording the pH at 10 minute intervals, for 96 hours. Once the recording of rumen pH was complete the cows were again secured in the crush and the loggers were removed and replaced by the original cannula plug.

Loggers were washed and dried in the laboratory. Loggers were then connected to the Omnilog Data Management Program where all the collected data was transferred to an excel file which could be processed at a later stage. The average pH values over 30 minute intervals over

the four days of recording were calculated.

During the second period of the rumen study care was taken to allocate the same logger to the same cow, as allocated in the first period so as to avoid any variations due to external factors.

4.3.2.2 Rumen liquor samples

Rumen liquor samples were collected on day five of the two collection periods, from each of the cannulated cows. Samples were collected in duplicate for the analysis of NH_3-N and volatile fatty acid (VFA). Samples were collected at 07:00, 13:30 and 20:00. Cows were placed in a crush while samples were collected. Clearly marked bottles were attached, in succession, to a hand pump. A 50 cm long, thin stainless steel pipe was attached to the hand pump via a thin rubber tube. The stainless steel pipe was inserted into the rumen, through the cannula, taking care not to insert the pipe too far and risk damaging the rumen wall. One person then operated the hand pump while another moved the pipe slowly up and down within the rumen. The action of the pump sucked the rumen liquor out through the pipe, into the marked bottles. The pH of the sample was then immediately measured using a calibrated portable pH logger (WTW pH 340i pH meter and data loggers with a WTW Sentix 41 pH electrode; Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany), after which samples were sealed. Once all cows had been sampled, the collected rumen liquor was taken into the laboratory. Here each sample was passed through a double layer of cheese cloth so as to remove the large solid particles. Aliquots of 20 ml of each sample was collected and placed into two, smaller, clearly labelled, airtight containers which were then frozen for future analyses of VFA and NH_3-N. A total of 96 samples were collected (48 samples for NH_3-N analysis and 48 samples for VFA analysis).

4.3.2.3 In sacco Dacron bag study

The *in sacco* Dacron bag study was carried out according to the technique described by Cruywagen (2006). A representative sample of the pasture was collected and dried at 60 °C for 72 hours. Dried pasture was then cut into 5 mm lengths. Nylon Dacron bags were clearly labelled and dried at 60 °C for 72 hours after which they were weighed directly from the oven. Five gram of the dried, cut pasture was then weighed out, on a tared scale, into the bag. The scale was tared again and the bag closed with a cable tie and weighed once more. Three bags were prepared for each cow at two different incubation times, namely 12 hours and 30 hours. Two extra bags (blanks) were prepared in the same manner, but did not undergo incubation. Three bags were then placed in each leg of a 40 decitex, ladies stocking, which was not of the “antimicrobial” type. A large marble (weight) was also included into the bottom of the stocking to ensure that the stockings penetrated the rumen contents. Stockings were fastened to the inside of the cannula plugs by means of an embedded metal ring.

After the morning milking session, cows were secured in the crush and the cannula plug

removed and replaced with the cannula plug to which the stockings had been attached. At the conclusion of the first incubation time (12 hours) the cannula plug was removed and one of the stockings legs pried free of the rumen contents and cut off. The other leg was inserted back into the rumen and the cannula plug replaced. Once back in the laboratory the Dacron bags were removed from the stocking and rinsed free of all rumen particulate matter and frozen. At the conclusion of the second incubation period (30 hours), the second stocking leg was removed and the original cannula plug replaced. These bags were also rinsed of any rumen particulate matter and frozen.

At a later stage the frozen bags were placed in water in a twin tub washing machine. The bags were washed in three five minute cycles with clean water. At the end of the washing cycles, bags were spun for three minutes to remove any excess water. Once the washing process was complete bags were placed into the drying oven at 60 °C for 72 hours. After drying, bags were weighed directly out of the oven, sealed in plastic bags and stored for later analysis of NDF.

4.4 Analytical procedures

4.4.1 High fibre concentrate supplement and pasture sample analysis

All samples and crucibles were weighed using the hot weighing technique. Even though Windham (1986) found no significant difference between the hot weighing technique and the desiccator technique when determining moisture content, the hot weighing technique showed a higher accuracy (SEM = 0.8g/kg) than the desiccator technique (SEM = 1.1g/kg). The hot weighing technique is also an easier process to perform and requires less time. This method was followed throughout the study.

All HF concentrate supplement and pasture samples were analysed in duplicate for DM (AOAC, 2002; method 934.01), ash (AOAC, 2002; method 942.05), CP (AOAC, 2002; method 990.03; using the Leco N analyser, model FP 528), NDF (Robertson & van Soest, 1981; using the Ankom fibre analysis system), ADF (Robertson & van Soest, 1981; Ankom fibre analysis system), ADL (Robertson & van Soest, 1981; Ankom fibre analysis system), NDICP (samples first analysed according to NDF procedure, residue then analysed for CP on Leco N analyser, model FP 528), ADICP (samples first analyse according to ADF procedure, residue the analysed for CP on Leco N analyser, model FP 528), EE (AOAC, 2002; method 920.39), GE (MC 1000 Modular Calorimeter, Energy Instrumentation, Sandton, South Africa, 2146), IVOMD (Buys *et al.*, 1996) and starch (AOAC, 2002; method 996.11).

4.4.2 Milk samples

Milk samples were sent to Lactolab, ARC, Irene where they were analysed for milk fat, protein, lactose, MUN and SCC. Milk fat, protein and lactose were analysed with the Bentley FTS

(Bentley Instruments Inc., Minnesota, USA, 55318) by means of the Fourier Transform Spectrometer technology. MUN was analysed by use of the ChemSpec 150 (Bentley Instruments Inc., Minnesota, USA, 55318) which uses a modified Berthelot reaction. Somatic cell count was analysed with the Somacount FCM (Bentley Instruments Inc., Minnesota, USA, 55318) by means of flow cytometry.

4.4.3 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 first 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.

4.4.4 Dacron bag study

The residue in the Dacron bags was used for the determination of NDF concentration. The content of three bags prepared for a specific incubation time and a specific cow were pooled. Samples were then analysed according to the NDF procedure mentioned in 4.4.1.

4.5 Statistical analyses

Data of cows used in the production study were subjected to a complete randomised block design, while data of cows used in the rumen study were subjected to a cross over design. Milk production, milk composition, LW and BCS data were subjected to an appropriate analysis of variance (ANOVA). Co-variance was not included into the analysis of variance as cows were blocked before the study according to milk production, lactation number and DIM. Rumen VFA and *in sacco* Dacron bag study data was subjected to a main effects ANOVA. Rumen pH was subjected to a Repeated Measures ANOVA. All analysis was done with the aid of the GLM procedure of SAS, Version 9.2 (SAS, 2008).

The null hypothesis was: Ho: $\mu_1 = \mu_2 = \mu_3 = \mu_a$ The null hypothesis was rejected where $p < 0.05$. Student's t tests were used to confirm the results of the ANOVA and compare the treatment means at a 5 % significance level. Least squares means were used to calculate a pooled standard error of treatment means. Shapiro Wilk tests were used to test for normality (Shapiro & Wilk, 1965).

4.6 References

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5 Results

5.1 Production study

5.1.1 Milk yield and composition

Milk yield and milk composition results are presented in Table 5. The milk yield of cows on treatment MC did not differ from that of cows on the LC and HC treatments, while cows on the HC treatment produced more milk than those in the LC treatment. Treatment had no effect on 4 % FCM, ECM and milk protein content. The HC treatment resulted in lower milk fat, lactose and MUN contents.

Table 5 Mean milk yield and milk composition (fat, protein, lactose, SCC and MUN) of cows receiving different amounts of a high fibre concentrate supplement (n = 16)

Parameter[1]	Treatment[2]			SEM[3]	p-value
	LC	MC	HC		
Milk yield (kg cow^{-1} day^{-1})	16.18^{a}	17.25^{ab}	18.12^{b}	0.486	0.029
4 % FCM (kg cow^{-1} day^{-1})	18.37	19.66	19.60	0.473	0.110
ECM (kg cow^{-1} day^{-1})	19.56	20.94	20.96	0.500	0.093
Fat (%)	4.92^{a}	4.96^{a}	4.58^{b}	0.092	0.014
Protein (%)	3.61	3.63	3.54	0.042	0.306
Lactose (%)	4.68^{a}	4.64^{a}	4.52^{b}	0.025	< 0.001
SCC (x 1000 mL^{-1})	175	211	206	24.84	0.602
MUN (mg dL^{-1})	11.62^{a}	11.55^{a}	9.95^{b}	0.369	0.004

[1] FCM - Fat corrected milk; ECM - Energy corrected milk; SCC - Somatic cell count; MUN - Milk urea nitrogen
[2] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; MC - Medium concentrate treatment receiving 7 kg (as is) high fibre concentrate supplement and 7 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[3] SEM - Standard error of the mean
[a, b] Means in the same row with different superscripts differ (P < 0.05)

5.1.2 Live weight and body condition score

The LW and BCS results before and after the study are presented in Table 6. The LW before and after the study did not differ between any of the treatments. Cows on treatment LC experienced a larger change in LW over the duration of the study than cows on treatment MC and HC. Cows on treatment LC also had a higher ADG over the duration of the study than cows on treatment MC and HC. The BCS before and after the study as well as the change in BCS did not differ between any of the treatments.

Table 6 Mean LW and BCS before and after the study of cows receiving different amounts of a high fibre concentrate supplement (n = 16)

Parameter[1]	Treatment[2]			SEM[3]	p-value
	LC	MC	HC		
LW before (kg)	353	362	361	6.967	0.563
LW after (kg)	396	382	380	9.137	0.404
LW change (kg)	+ 43.5[a]	+ 19.4[b]	+ 18.7[b]	4.113	< 0.001
ADG (kg day^{-1})	0.62[a]	0.28[b]	0.27[b]	0.059	< 0.001
BCS before	2.34	2.30	2.23	0.062	0.461
BCS after	2.66	2.58	2.42	0.107	0.301
BCS change	+ 0.31	+ 0.28	+ 0.19	0.082	0.537

[1] LW - Live weight; ADG - Average daily gain; BCS - Body condition score
[2] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; MC - Medium concentrate treatment receiving 7 kg (as is) high fibre concentrate supplement and 7 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[3] SEM - Standard error of the mean
[a, b] Means in the same row with different superscripts differ (P < 0.05)

5.1.3 High fibre concentrate supplement intake and nutrient composition

The daily allowance and actual intake of the HF concentrate supplement is presented in Table 7. The expected chemical composition of the HF concentrate supplement was shown in Table 4, but the actual composition, based on samples collected throughout the study, is presented in Table 8.

Table 7 High fibre concentrate supplement allowance and actual DM intake throughout the study period for all three high fibre concentrate supplement treatments

Parameter[1]	Treatment[2]		
	LC	MC	HC
Fed (kg as is day^{-1})	4	7	10
Actual intake (kg DM day^{-1})	3.60	6.29	8.99

[1] DM - Dry matter
[2] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; MC - Medium concentrate treatment receiving 7 kg (as is) high fibre concentrate supplement and 7 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day

Table 8 Mean (± s.d.) quality of high fibre concentrate supplement samples collected over an eight week period (n = 4)

Parameter	g kg^{-1} DM[1]
Dry matter	899 ± 13.3
Organic matter	920 ± 2.1
Ether extract	41.6 ± 5.27
Metabolisable energy (MJ kg^{-1} DM)	10.9 ± 0.15
Crude protein	145 ± 1.3
Starch	339 ± 2.9
Neutral detergent fibre	231 ± 8.9
Acid detergent fibre	87.2 ± 23.59
Acid detergent lignin	12.3 ± 1.51
Neutral detergent insoluble crude protein	54.4 ± 1.05
Acid detergent insoluble crude protein	66.0 ± 0.37
In vitro organic matter digestibility	787 ± 11.1

[1] DM - Dry matter

5.1.4 Pasture samples

5.1.4.1 Pasture nutrient composition

The quality of the pastures grazed by each treatment throughout the study period is presented in Table 9. There was no great variation between the different pastures grazed and pasture quality was mostly uniform.

Table 9 Mean (± s.d.) pasture quality of samples collected over an eight week period for the three high fibre concentrate supplement treatments (n = 4)

Parameter[1]	Treatment[2]		
	LC	MC	HC
DM (g kg^{-1})	138 ± 19.8	137 ± 14.6	139 ± 10.93
OM (g kg^{-1} DM)	869 ± 17.0	877 ± 9.66	884 ± 8.76
EE (g kg^{-1} DM)	24.1 ± 2.96	26.8 ± 10.70	22.8 ± 5.62
ME (MJ kg^{-1} DM)	12.0 ± 0.15	12.7 ± 0.92	12.2 ± 0.80
CP (g kg^{-1} DM)	237 ± 63.6	239 ± 38.6	238 ± 53.5
NDF (g kg^{-1} DM)	408 ± 3.79	419 ± 9.93	411 ± 16.8
ADF (g kg^{-1} DM)	236 ± 12.7	244 ± 11.2	247 ± 5.39
ADL (g kg^{-1} DM)	25.5 ± 8.64	31.2 ± 5.78	20.8 ± 11.81
NDICP (g kg^{-1} DM)	143 ± 45.8	140 ± 32.9	156 ± 42.8
ADICP (g kg^{-1} DM)	99.9 ± 35.1	102 ± 28.3	108 ± 24.3
IVOMD (g kg^{-1} DM)	827 ± 5.2	825 ± 4.07	825 ± 21.5

[1]DM - Dry matter, OM - Organic matter, EE - Ether extract, ME - Metabolisable energy, CP - Crude protein, NDF - Neutral detergent fibre, ADF - Acid detergent fibre, ADL - Acid detergent lignin, NDICP - Neutral detergent insoluble crude protein, ADICP - Acid detergent insoluble crude protein, IVOMD - *In vitro* organic matter digestibility

[2] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; MC - Medium concentrate treatment receiving 7 kg (as is) high fibre concentrate supplement and 7 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day

Figure 5 is a graphical representation of the change in pasture quality from winter to spring. The data points were calculated by combining all samples collected within a specific two week period.

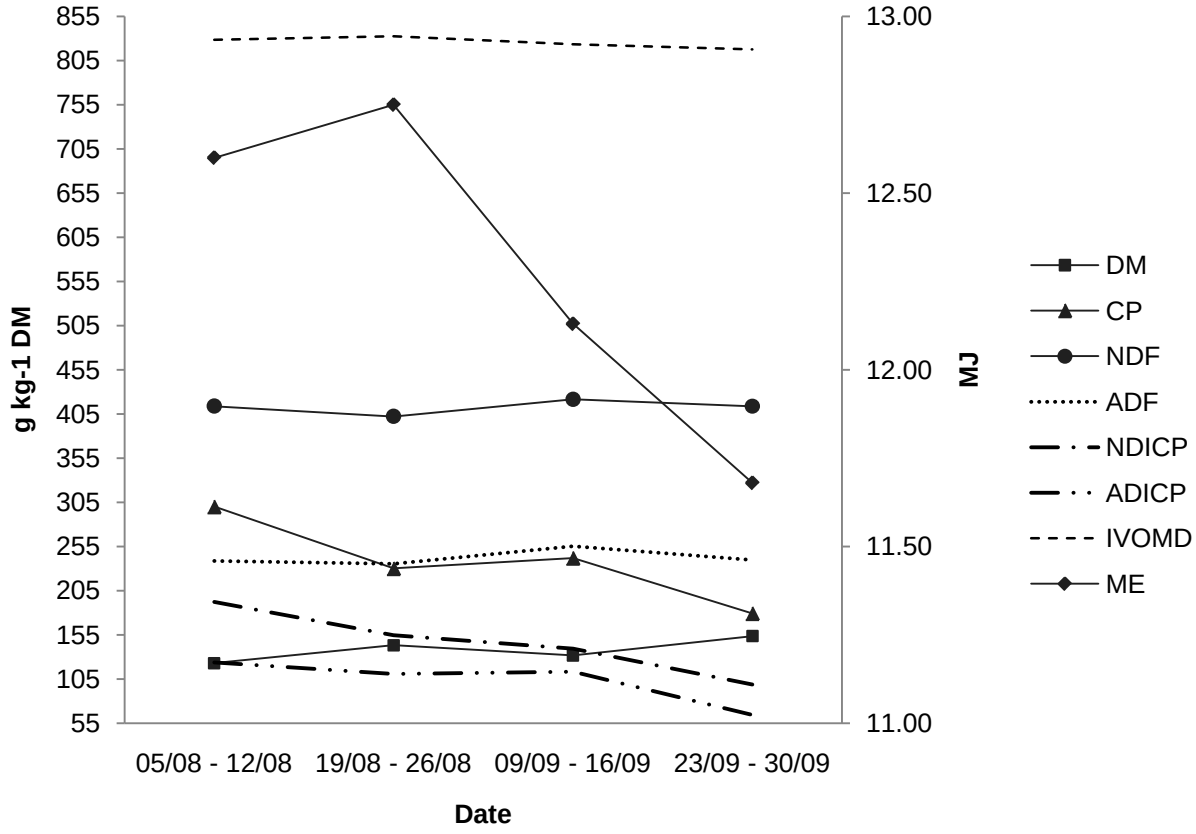

Figure 5 The response of pasture quality parameters to the changing of the season from winter to spring of samples collected over an eight week period during the study (n = 3)

5.1.4.2 Pasture allocation and intake

Parameters used for the allocation of pasture and the estimation of intake are shown in Table 10. The rising plate meter (RPM) reading before grazing did not differ between treatments. After grazing however, treatment LC had a higher RPM than treatment MC and HC. The pasture yield before and after grazing was calculated using the regression equation, which was obtained from a series of cuttings during the trial: Y = 91.06 * H – 200.59, where Y = DM yield and H = RPM reading. Pasture yield before grazing did not differ between treatments. After grazing treatment LC had a higher pasture yield than treatment MC and HC. The amount of pasture allocated differed between all three treatments. Pasture allocation was highest for treatment LC, followed by treatment MC, while the lowest amount of pasture was allocated for treatment HC. Pasture intake is correlated to pasture allocation; therefore pasture intake differed between all three treatments. Pasture consumption was highest by cows on treatment LC than cows on treatment MC, while cows on treatment HC had the lowest consumption.

Table 10 Mean RPM readings and pasture yield before and after grazing of three high fibre concentrate supplement treatments grazing kikuyu over-sown with ryegrass

Parameter[1]	Treatment[2]			SEM[3]	p-value
	LC	MC	HC		
Before grazing					
RPM reading	27.5	27.6	26.3	0.739	0.395
Pasture yield (kg DM ha^{-1})	2302	2310	2191	67.25	0.395
Allocated pasture (kg DM cow^{-1} day^{-1})	14.1^{a}	10.7^{b}	8.3^{c}	0.233	<0.001
After grazing					
RPM reading	11.5^{a}	10.7^{b}	10.6^{b}	0.301	0.045
Pasture yield (kg DM ha^{-1})	848^{a}	774^{b}	767^{b}	27.315	0.045
Pasture intake (kg DM cow^{-1} day^{-1})	8.66^{a}	6.94^{b}	5.02^{c}	0.175	<0.001
Pasture removed (kg DM ha^{-1})	1474	1508	1454	69.259	0.855

[1] RPM - Rising plate meter; DM - Dry matter
[2] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; MC - Medium concentrate treatment receiving 7 kg (as is) high fibre concentrate supplement and 7 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[3] SEM - Standard error of the mean
[a, b] Means in the same row with different superscripts differ (P < 0.05)

5.1.4.3 Pasture growth rate

Figure 6 depicts the average growth rate (kg DM ha^{-1} day^{-1}) of the kikuyu over-sown with ryegrass pasture which was utilised throughout the study. The growth rate in September (64.4 kg DM ha^{-1} day^{-1}) was almost twice that of the growth rate in July (34.6 kg DM ha^{-1} day^{-1}).

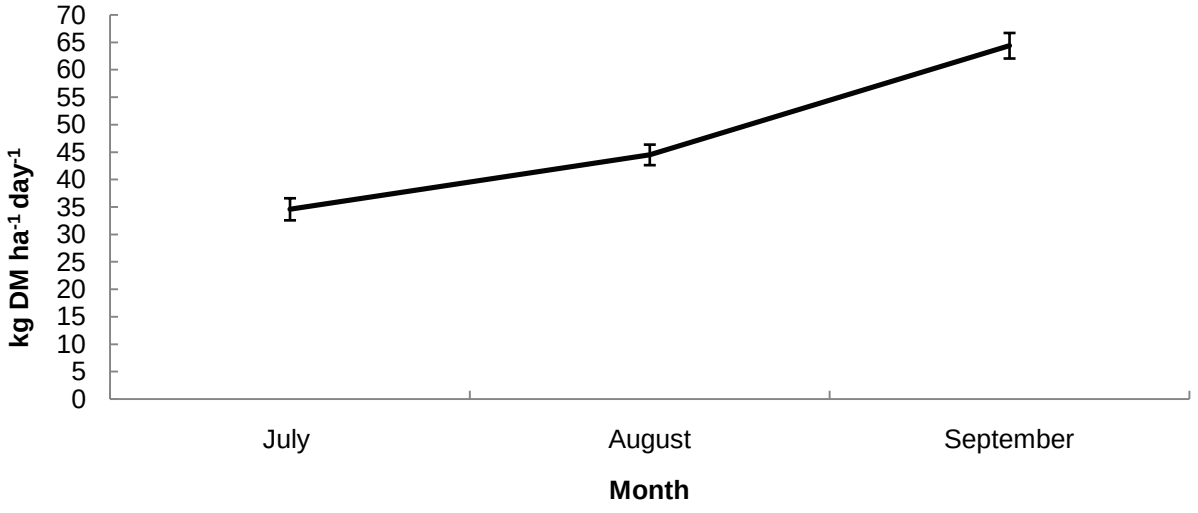

Figure 6 Growth rate (kg dry matter hectare^{-1} day^{-1}) of the kikuyu over-sown with ryegrass pasture which was utilised throughout the study, error bars represent SEM

5.2 Rumen study

5.2.1 Rumen pH profiles

The rumen pH recorded during the rumen study period is presented in Figure 7. Throughout the day the rumen pH of cows on treatment LC did not differ to the rumen pH of cows on treatment HC. Standard error of the means (SEM) are not an indication of significance and are included in the graph as error bars, as such all $p > 0.05$. There is also a distinctive drop in pH for both treatments at 08:30 and 14:30 which coincides with the feeding of the HF concentrate supplement in the milking parlour. The highest pH was reached just before the morning milking session and the lowest after the afternoon milking session.

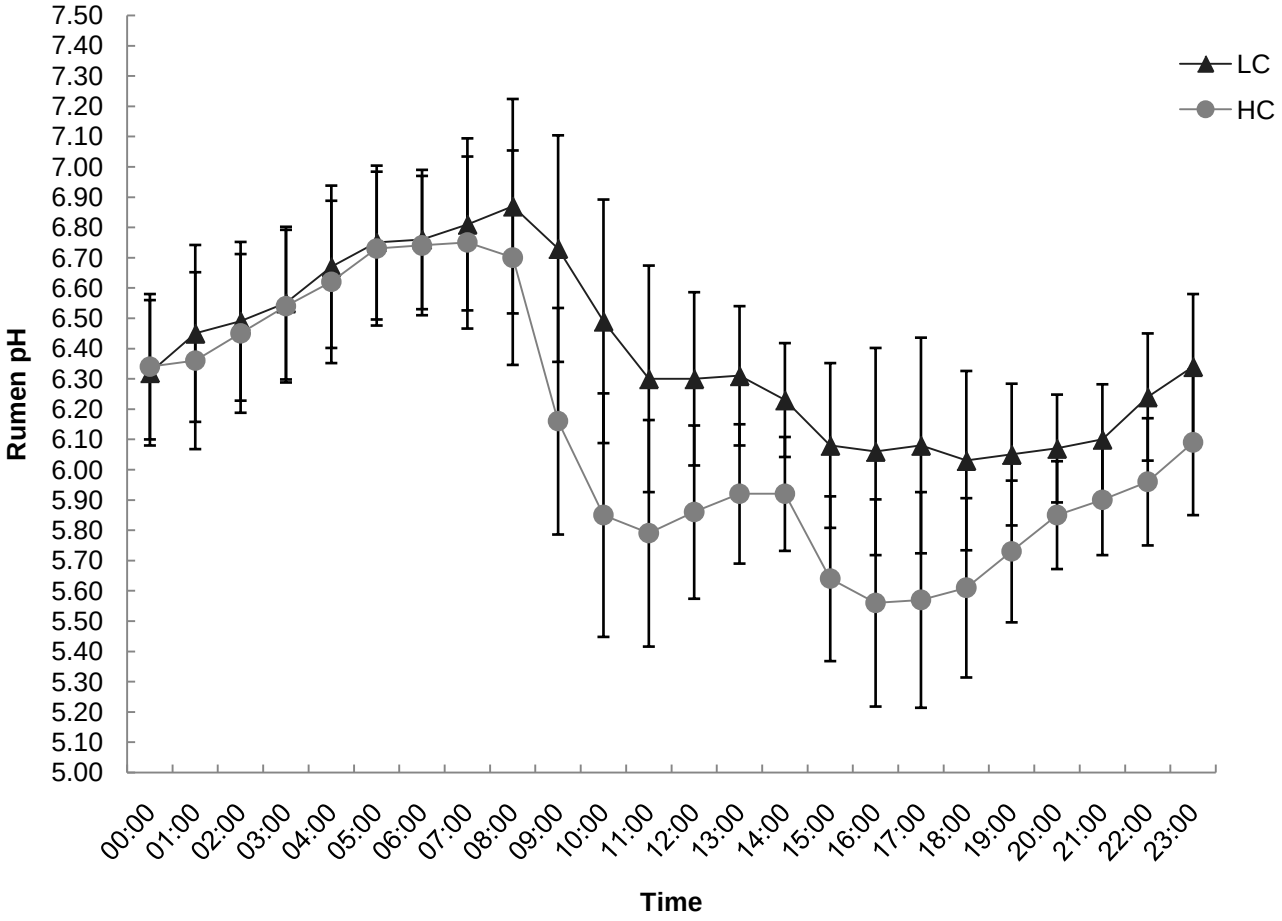

Figure 7 Diurnal fluctuations of the ruminal pH of cows (n = 8) in two high fibre concentrate supplement treatments, error bars represent SEM (LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day)

The number of hours which the rumen pH spent below 6.2, 6.0 and 5.8 is presented in Table 11. The number of hours spent below pH 6.2 did not differ between treatment LC and treatment

HC. The rumen pH of treatment HC did however spend more time below pH 6.0 and pH 5.8 than treatment LC.

Table 11 Mean time (hours) that the rumen spent below a specific pH (6.2, 6.0 and 5.8) of cows (n = 8) in two high fibre concentrate supplement treatments

pH	Treatment[1]		SEM[2]	p-value
	LC	HC		
< 6.2	11.7	15.1	1.161	0.173
< 6.0	7.21	12.2	0.980	0.034
< 5.8	2.64	7.43	0.987	0.031

[1] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[2] SEM - Standard error of the mean

5.2.2 Rumen liquor samples

5.2.2.1 Volatile fatty acid profiles

The mean ruminal concentration (mM L^{-1}) of acetate, propionate and butyrate measured for three time intervals during the rumen study are presented in Table 12. Cows on treatment HC had a lower acetate concentration than cows on treatment LC at all three time intervals. Cows on treatment HC had a higher concentration of propionate than cows on treatment LC only at time interval 13:00. The butyrate concentration did not differ between cows on treatment LC and HC at any one of the time intervals.

Table 12 Mean ruminal concentration (mM L^{-1}) of acetate, propionate and butyrate measured at three time intervals of cows (n = 8) in two high fibre concentrate supplement treatments

Volatile fatty acid	Time	Treatment[1]		SEM[2]	p-value
		LC	HC		
Acetate	07:00	66.07	53.88	2.678	0.018
	13:30	77.68	71.36	1.439	0.021
	20:00	81.57	69.64	1.897	0.004
Propionate	07:00	21.03	23.24	1.022	0.177
	13:30	31.18	35.78	1.105	0.026
	20:00	36.50	35.87	1.207	0.727
Butyrate	07:00	16.42	15.33	1.103	0.510
	13:30	21.88	23.56	0.960	0.264
	20:00	24.00	24.28	1.449	0.896

[1] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[2] SEM - Standard error of the mean

Ruminal acetate and propionate ratios over three time intervals are presented in Table 13. Cows on treatment HC had a lower acetate to propionate ratio than cows on treatment LC at all three time intervals. This corresponds to the findings in Table 12.

Table 13 Ruminal acetate and propionate ratios measured at three time intervals of cows (n = 8) in two high fibre concentrate supplement treatments

Time	Treatment[1]		SEM[2]	p-value
	LC	HC		
07:00	3.18	2.36	0.133	0.005
13:30	2.56	2.08	0.067	0.002
20:00	2.25	2.00	0.068	0.037

[1] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[2] SEM - Standard error of the mean

The mean ruminal concentration (mM L^{-1}) of valerate, isobutyrate and isovalerate measured for three time intervals during the rumen study are presented in Table 14. Cows on treatment HC had a higher concentration of valerate than cows on treatment LC at all three time intervals. The isobutyrate and isovalerate concentration did not differ between cows on treatment LC and HC at

any one of the time intervals.

Table 14 Mean ruminal concentration (mM L^{-1}) of valerate, isobutyrate and isovalerate measured at three time intervals of cows (n = 8) in two high fibre concentrate supplement treatments

Volatile fatty acid	Time	Treatment[1]		SEM[2]	p-value
		LC	HC		
Valerate	07:00	4.86	5.62	0.215	0.046
	13:30	5.50	7.37	0.34	0.008
	20:00	5.92	7.84	0.394	0.014
Isobutyrate	07:00	4.81	4.83	0.117	0.943
	13:30	4.81	4.83	0.059	0.82
	20:00	4.53	4.77	0.091	0.114
Isovalerate	07:00	9.38	9.28	0.268	0.800
	13:30	9.64	8.65	0.774	0.402
	20:00	9.42	9.53	0.164	0.659

[1] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[2] SEM - Standard error of the mean

5.2.2.2 Ammonia nitrogen profile

The mean NH_3-N concentration (mg dL^{-1}) measured at three time intervals during the rumen study are presented in Table 15. The NH_3-N concentration did not differ between cows on treatment LC and HC at any one of the time intervals.

Table 15 Mean ammonia nitrogen concentration (mg dL^{-1}) measured at three time intervals of cows (n = 8) in two high fibre concentrate supplement treatments

Time	Treatment[1]		SEM[2]	p-value
	LC	HC		
07:00	18.9	16.3	1.8907	0.370
13:30	29.6	26.1	2.7945	0.411
20:00	26	27.4	1.4513	0.524

[1] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[2] SEM - Standard error of the mean

5.2.2.3 pH

The mean pH values measured for three time intervals during the rumen study are presented in Table 16. These pH values were recorded using a portable pH logger as described in 4.3.2.1. Cows on treatment HC had a lower ruminal pH than cows on treatment LC at time interval 13:30. The ruminal pH did not differ between cows on treatment LC and HC for time interval 07:00 and 20:00.

Table 16 Mean ruminal pH values measured at three time intervals, using a portable pH logger, of cows (n = 8) in two high fibre concentrate supplement treatments

Time	Treatment[1]		SEM[2]	p-value
	LC	HC		
07:00	6.82	6.70	0.0537	0.189
13:30	6.03	5.77	0.0474	0.008
20:00	5.70	5.75	0.0807	0.722

[1] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[2] SEM - Standard error of the mean

5.2.2.4 Summary

A summary of all the data obtained from the rumen liquor samples can be seen in Table 17. The rumen contents of cows on treatment LC had a higher mean daily concentration of acetate than those cows on treatment HC. The acetate to propionate ratio, as well as the molar % of acetate, was higher in the cows on the LC treatment. The other VFA were not affected by treatment.

Table 17 Mean daily ruminal VFA, NH_3-N and pH measurements of cows (n = 8) in two high fibre concentrate supplement treatments

Parameter[1]	Treatment[2]		SEM[3]	p-value
	LC	HC		
Total VFA	145.07	138.55	2.933	0.167
Acetate (mM L^{-1})	75.11	64.96	1.75	0.006
Propionate (mM L^{-1})	29.57	31.63	0.942	0.173
Butyrate (mM L^{-1})	20.77	21.06	1.026	0.85
Valerate (mM L^{-1})	5.43	6.94	0.299	0.012
Isobutyrate (mM L^{-1})	4.72	4.81	0.054	0.287
Isovalerate (mM L^{-1})	9.48	9.15	0.341	0.523
Acetate:Propionate	2.67	2.15	0.086	0.005
Total VFA molar %				
Acetate %	51.91	47.02	1.64	0.002
Propionate %	20.09	22.61	1.374	0.018
Butyrate %	14.18	14.93	1.29	0.343
Valerate %	3.79	5.09	0.674	0.015
Isobutyrate %	3.34	3.59	0.214	0.085
Isovalerate %	6.69	6.75	0.5	0.819
pH				
Hand held logger	6.18	6.07	0.053	0.19
Data logger	6.38	6.11	0.127	0.286
NH_3-N (mg dL^{-1})	24.82	23.26	1.655	0.529

[1] VFA - Volatile fatty acids; NH_3-N - Ammonia nitrogen
[2] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[3] SEM - Standard error of the mean

The relationship between total ruminal VFA concentration, ruminal NH_3-N concentration and ruminal pH is depicted in Figure 8. The total ruminal VFA and ruminal NH_3-N concentrations increased as pH decreased.

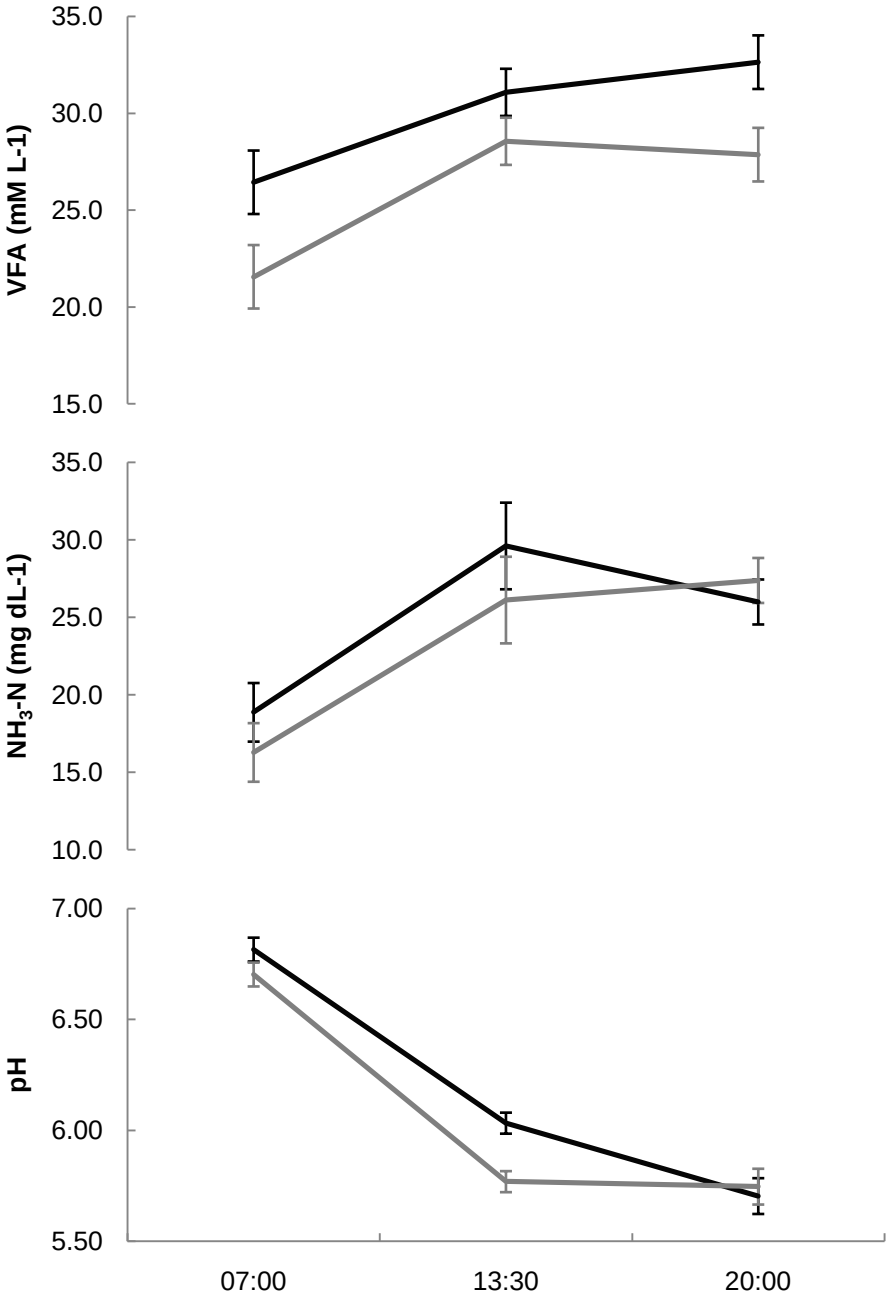

Figure 8 Total ruminal volatile fatty acid concentration, ruminal ammonia-nitrogen concentration and ruminal pH of two high fibre concentrate supplement treatments at three time intervals (Black line - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; Grey line - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day)

5.2.3 In sacco Dacron bag study

5.2.3.1 Dry matter disappearance

The DM disappearance of pasture samples that were incubated in the rumen for 12 and 30 hours is presented in Figure 9. DM disappearance was lower for cows on treatment HC than those in treatment LC.

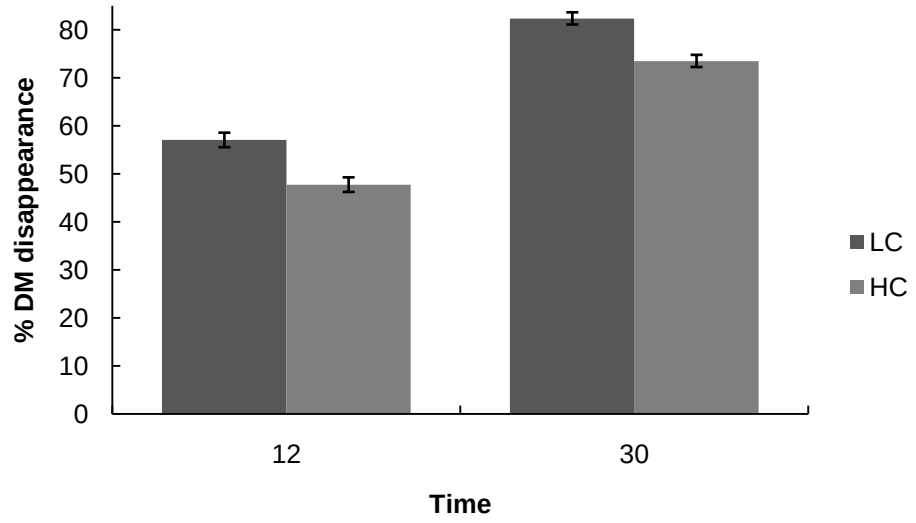

Figure 9 Mean % of dry matter (DM) disappearance of pasture at 12 and 30 hours of incubation within the rumen of cows (n = 8) for two high fibre concentrate supplement treatments, error bars represent SEM (LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day)

5.2.3.2 Neutral detergent fibre disappearance

The NDF disappearance of pasture samples that were incubated in the rumen for 12 and 30 hours is presented in Figure 10. At 12 hours of incubation there was no difference in the NDF disappearance between cows on treatment LC and HC. After 30 hours of incubation, NDF disappearance was higher for cows on treatment LC than those in treatment HC.

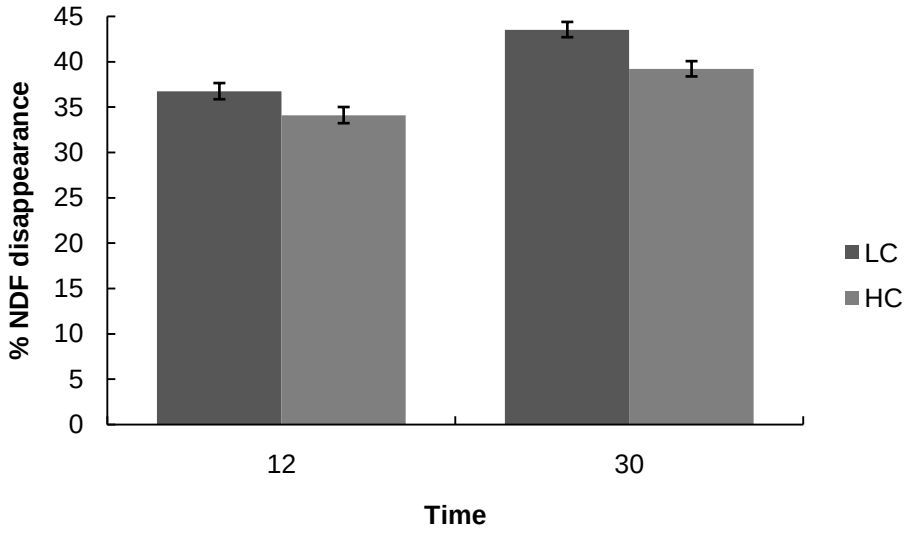

Figure 10 Mean % of neutral detergent fibre (NDF) disappearance of pasture at 12 and 30 hours of incubation within the rumen of cows (n= 8) for two high fibre concentrate supplement treatments, error bars represent SEM (LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day)

5.3 Regression

The regression equation which was cut throughout the duration of the study yielded the following equation: Y = 91.06 * H – 200.59, where Y = DM yield and H = RPM reading, Figure 11. This regression equation was only used once the study had concluded, for the improvement of the estimations of pasture intake as it refers directly to the pasture used during the study. This equation also explains 77.9% of the variation experienced through sampling.

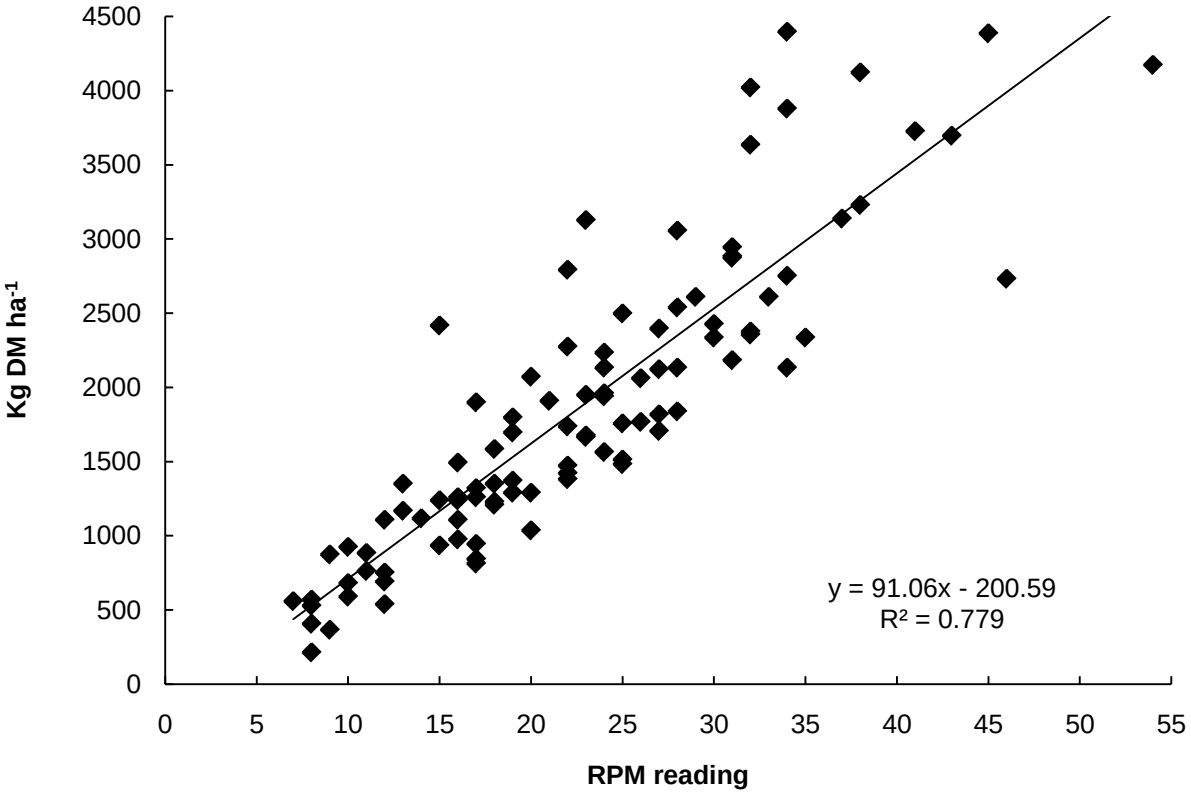

Figure 11 The relationship between the rising plate meter (RPM) reading and the pasture yield (kg dry matter hectare^{-1}) of kikuyu over-sown with ryegrass pasture used throughout the study

5.4 Stocking rate

The mean grazing days per cycle and stocking rates calculated throughout the research period are recorded in Table 18. Treatment LC had a larger area of pasture than treatment MC and HC. Treatment LC had fewer days per grazing cycle than treatment MC and HC. The stocking rate differed between each treatment; with treatment LC having the lowest stocking rate and treatment HC having the highest stocking rate. The % pasture which was saved was also calculated in relation to treatment LC.

Table 18 The farmlet size, mean grazing days per cycle, mean stocking rates and % pasture saved of three high fibre concentrate supplement treatments

Parameter	Treatment[1]			SEM[2]	p-value
	LC	MC	HC		
Farmlet size (ha)	3.57	2.92	2.20	-	-
Grazing days cycle^{-1}	34.7^{a}	38.4^{b}	37.6^{b}	1.033	0.009
Stocking rate (cows ha^{-1} cycle^{-1})	5.07^{a}	6.07^{b}	7.64^{c}	0.278	<0.001
Pasture saved (%)	0	22.3	36.7	-	-

[1] LC - Low concentrate treatment receiving 4 kg (as is) high fibre concentrate supplement and 10 kg DM pasture per day; MC - Medium concentrate treatment receiving 7 kg (as is) high fibre concentrate supplement and 7 kg DM pasture per day; HC - High concentrate treatment receiving 10 kg (as is) high fibre concentrate supplement and 5 kg DM pasture per day
[2] SEM - Standard error of the mean
[a, b] Means in the same row with different superscripts differ ($P < 0.05$)

6 Discussion

6.1 Production study

6.1.1 Milk yield

Milk production of cows throughout the study and over all three treatments was lower than expected when the high levels of concentrate supplement feeding are taken into account (Table 5). It would seem that the low maize inclusion level and high NDF content of the HF concentrate supplement could have been the cause. However, Miron *et al.* (2004) and Lingnau (2011) both found that replacing maize grain with a non-forage fibre source such as wheat bran or hominy chop did not decrease milk production when compared to a diet with no inclusion of a non-forage fibre source.

The smaller milk response by cows on the HC treatment than expected could be as a result of the higher level of ME consumed, although the availability of the ME is questionable (Sairanen *et al.*, 2006). Kellaway & Porta (1993) and Sairanen *et al.* (2006) both stated that the increase in milk production per kg of concentrate supplement decreases as the level of concentrate supplement increases. As such the milk response of cows on treatment HC was not remarkable compared to cows on treatment LC and did not differ at all from cows on treatment MC.

6.1.2 Milk composition

6.1.2.1 Milk fat content

Milk fat content decreased as HF concentrate supplement feeding level increased (Table 5). The HF concentrate supplement had a high level of NDF (230.61 ± 8.88 g kg^{-1} DM). This NDF would result in an increase in acetate and butyrate production, ultimately increasing the milk fat content (McDonald *et al.*, 2002). Bargo *et al.* (2003) and Sayers *et al.* (2003) found an increase in milk fat content when a high fibre concentrate supplement was fed to cows on pasture. However, when a concentrate supplement (even a HF concentrate) is fed at such high levels as was done during the current study, a drop in rumen pH is expected and cellulolytic bacteria may become less active, acetate and butyrate concentration may decrease resulting in possible milk fat content decreases (Hoover, 1986; Van Soest *et al.*, 1991), hence the lower milk fat content of cows on treatment HC. High quality pasture, such as the ryegrass pasture grazed during the study, is characterized as providing less peNDF, which further contributed to the decrease in rumen pH and the subsequent lower milk fat content of cows on treatment HC (Bargo *et al.*, 2003; Plaizier *et al.*, 2009). The VFA data obtained during the rumen study corresponds to the lower milk fat content of cows on the HC treatment (Table 17). Increasing the level of concentrate supplementation (even a HF concentrate supplement) will result in an increase in propionate production at the expense of

acetate production, resulting in a lower milk fat content (Carruthers & Neil, 1997; Sairanen *et al.*, 2006). Therefore a shift in VFA production in the rumen of cows on the HC treatment was also a contributing factor to lowering the milk fat content. This corresponds to the VFA data obtained (Table 12).

6.1.2.2 Milk protein content

No differences were recorded for protein content between the three different treatments (Table 5). Milk protein levels do not respond readily to dietary manipulation (Bargo *et al.*, 2003; Kellaway & Harrington, 2004), as such no differences were expected. According to Logix Milk (Suretha Francis, suretha@studbook.co.za, 2012) the average milk protein content of Jersey cows in South Africa is 3.85 %. In a study by Erasmus (2009) milk protein content of 3.84 % was recorded for Jersey cows grazing kikuyu over-sown with Annual Italian ryegrass, however, during the winter months of July to September milk protein content only reached 3.4 - 3.6 %.

The milk protein content obtained during the current study was much lower than that recorded by Logix Milk and the year average obtained by Erasmus (2009). The milk protein content obtained during this study does however correspond to winter month's values obtained by Erasmus (2009). The lower milk protein content observed during the winter months and in the current study is due to the lower intake of readily fermentable carbohydrates. Lower intake of readily fermentable carbohydrates partially inhibit rumen micro-organism activity and lowers the synthesis of microbial protein; providing less essential AA required for milk protein synthesis (Khalili & Sairanen, 2000; Bargo *et al.*, 2002; Sayers *et al.*, 2003; Schwab *et al.*, 2008).

6.1.2.3 Lactose content

Cows on treatment HC had a lower lactose content than cows on treatment LC and MC (Table 5). According to Sutton (1989) and Kennelly & 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. One of the only factors which could result in a change in lactose content is the SCC or the health of the udder (Kitchen, 1981; Welper & Freeman, 1992). Milk volume in the mammary gland will increase, disproportionally to lactose yield and in response to the SCC, resulting in a decrease in lactose content.

The lactose content of cows on both treatment MC and HC fell below the expected content as stated by Gibson (1989) and NRC (2001). Both these treatments had elevated SCC (6.1.2.4), which could explain the lowered lactose content (Kitchen, 1981). Sutton (1989) and Welper & Freeman (1992) also stated that, when significant differences are found in lactose content, it is as a result of the low coefficient of variation of lactose, which highlights the low variability of lactose content in milk. Due to the low variability and high accuracy of lactose measurements, the unexpected significant difference in lactose content is unlikely to be as a result of incorrect

sampling or analysis. As such the difference in lactose content as well as the low lactose content remains an enigma.

6.1.2.4 Somatic cell count

There was no significant difference between the SCC of the three different treatments (Table 5) and all values obtained fall below the legal requirement of SCC for human consumption (< 500 000 cells per mL milk) (De Villiers *et al.*, 2000). Increased SCC could be a risk when cows are under high stocking rates, especially for a long duration of time. Increased stocking rate, as a result of lowered pasture allowance, could lead to a higher level of defaecation and urination. The less desirable conditions on the pasture could lead to slight increase in SCC as the cows would be more exposed to bacteria in the environment.

6.1.2.5 Milk urea nitrogen

Trevaskis & Fulkerson (1999) reported a positive correlation between MUN and the ratio of nitrogen to water soluble carbohydrates in pasture. The higher MUN values obtained for cows on treatment LC and MC (Table 5) could be due to the higher level of pasture intake compared to cows on treatment HC. However the lower MUN concentration of cows on treatment HC does not hold any biological significance as it still falls within the accepted range of 8 - 12 mg dL^{-1} (Kohn, 2007).

6.1.3 Live weight and body condition score

The high ADG of cows on treatment LC (Table 6) was unexpected as live weight changes are not generally observed in such a short period of time as would comprise a nutrition trial (Bargo *et al.*, 2002). Body condition score is the preferred measurement used to evaluate the ability of a diet or feeding strategy to meet basal metabolic requirements. The BCS gained during the trial did not differ between the three treatments indicating that all three feeding strategies were able to sustain milk production as well as allowing, to a small degree, the build-up of body reserves.

6.1.4 High fibre concentrate supplement nutrient composition

The nutritive composition results obtained for the HF concentrate supplement (Table 8) corresponds well to the initial estimations made by NOVA feeds when the supplement was formulated (Table 4). The HF concentrate supplement fed was very similar to the low starch concentrate supplement used by Lingnau (2011) except for a much higher inclusion level of wheat bran (18 % vs. 39.1 %).

The starch content obtained for the HF concentrate supplement fed during this study corresponds well to the starch content for the low starch concentrate supplement fed by Lingnau (2011) (33.8 % vs. 37.1 %). The emphasis was on a concentrate supplement which was high in

fibre but low in starch. These two factors are generally negatively correlated. This relationship in nutrient composition can be seen in the three concentrate supplements used by Lingnau (2011) where the starch content decreases as the NDF content increases. A low starch content and a subsequently high NDF content are essential when a concentrate supplement is fed at high levels as was done in this study. Feeding more than 6 kg concentrate supplement per day to cows on pasture increases the risk of acidosis and lowered rumen function. By lowering the starch content less readily fermentable carbohydrates are available to the micro-organisms for rapid degradation in the rumen and a sharp drop in the rumen pH is avoided, which allows for a higher level of concentrate supplement feeding. This corresponds to the rumen pH data obtained during this study where no differences in rumen pH were found between two different levels of feeding (6.2.1).

The ME value obtained for the HF concentrate supplement was much lower than the estimated value obtained from NOVA feeds (10.94 MJ ME vs. 12.18 MJ ME) however it does correspond to the ME value of the low starch concentrate supplement used by Lingnau (2011) (10.94 MJ vs. 10.95 MJ). Milk production was maintained at relatively high levels throughout the study; as such the ME of the HF concentrate supplement as well as that provided by pasture was sufficient to maintain milk production.

The degree to which NDF was able to maintain milk fat content will determine the eNDF of the HF concentrate supplement. From the milk composition data obtained during the study it is seen that milk fat content was maintained at a relatively high level (4.5 - 4.9 %), as such it can deduced that the HF concentrate supplement supplied a high level of eNDF. The peNDF of a feed is determined primarily by the ability of the feed to maintain rumen function. The rumen pH data (6.2.1) indicates that the peNDF was not sufficient to maintain rumen pH at all times, however there was no occurrence of clinical acidosis. This indicates that even though cows on treatment HC had a lower pH (6.2.1) and decreased DM and NDF digestion (6.2.3) than cows on treatment LC, there was sufficient fibre to maintain milk production and milk fat content. On a pasture based system the peNDF of the pasture itself must also be considered (6.1.5.1 and 6.1.5.2).

6.1.5 Pasture samples

6.1.5.1 Pasture nutrient composition

The quality of the pasture which was grazed during the study was very similar to data obtained by Meeske *et al.* (2006) and Van der Colf (2011) (Table 1). The data obtained from all the samples collected were used to compare the pasture grazed by cows on each treatment as well as to compare the nutritive composition of pasture as the season progressed.

The nutritive composition of the pasture (Table 9), when analysed for the three treatments, was similar and no major trend could be identified. As such any differences in milk production, milk composition or rumen parameters between cows on the three different treatments cannot be

attributed to the intake of pasture varying in quality. The nutritive composition of the pasture as the season progressed did show a trend (Figure 5). As the season progressed from winter to early spring the CP, NDICP, ADICP and ME as well as the digestibility of the pasture decreased. Consequently the DM, NDF and ADF increased. This decrease in pasture quality as the season progresses form winter to spring was expected (Bargo *et al.*, 2003; Meeske *et al.*, 2006; Fulkerson *et al.*, 2007; Van der Colf, 2011), once more highlighting the importance of adapting supplemental feeding throughout the year so as to bridge the nutritional gap (Delahoy *et al.*, 2003; Sayers *et al.*, 2003).

According to the specifications of Bargo *et al.* (2003) the pasture grazed during this study can be classified as a high quality pasture; 40 - 50 % NDF and > 18 % CP. High quality pasture is characterised as providing little peNDF, this is confirmed in the rumen pH data obtained during the rumen study (6.2.1) and emphasises the risk of providing cows with concentrate supplements.

6.1.5.2 Pasture allocation and intake

The average pasture yield before grazing was between 2191.41 kg DM ha^{-1} and 2301.58 kg DM ha^{-1} and was similar for all three treatments (Table 10). At this yield the ryegrass pasture is in the 3.5 - 4 leaf stage, which is the optimal time for defoliation (Booysen, 1966; Fulkerson & Donaghy, 2001; Irvine *et al.*, 2010). The pasture allocation shown in Table 10 is more than stated in the treatment specifications (4.2.1). This is due to the fact that the linear regression equation originally used for the allocation of the pasture was obtained from Van der Colf (2011). Pasture was allocated according to the linear regression equation of Van der Colf (2011) to meet treatment specifications. The values depicted in Table 10 were calculated using the linear regression equation which was generated from cuts collected during the current study. According to this linear regression equation more pasture was allocated than specified but the eventual pasture intake met the treatment specifications (4.2.1). Cows on treatment LC consumed the greatest amount of pasture, cows on treatment MC the second most and cows on treatment HC the least amount; this coincides with the treatment specifications. Cows on treatment LC and MC consumed less pasture than was predicted and according to the post-grazing rising plate meter (RPM) cows on treatment LC did not graze the pasture as efficiently as cows on treatment MC and HC. However the RPM of 11.5 for treatment LC still falls within the widely accepted range of 10 - 12 for post-grazing height and does not hold any practical or biological implications (Irvine *et al.*, 2010). The much lower pasture intake of cows on treatment HC was as a result of a lower pasture allowance. This is confirmed in the stocking rate data obtained (6.4). Providing cows with such a high level of HF concentrate supplement would normally result in substitution of pasture (Sairanen *et al.*, 2006), but through implementing lower pasture allowance and higher stocking rates there was no opportunity for substitution and the required pasture intake was enforced.

The disparity between pasture allocation and pasture intake (Table 10), regardless of the linear regression equation used, is due to the fact that a regression is normally cut at 3 cm above the ground, whereas cows generally only graze pasture up to 5 cm above the ground, resulting in an over estimation of pasture availability. Regressions are cut at 3 cm above the ground to offer some leeway if cows do graze below 5 cm. Disparity could also be contributed to the fact that pasture is trampled and contaminated with faeces and urine, lowering the potential pasture intake.

6.1.5.3 Pasture growth rates

The pasture growth rates obtained throughout the study period (Figure 6) were much higher than stated in the literature. According to Dickinson *et al.* (2004) a growth rate of only 15 kg ha^{-1} day^{-1} is expected during the winter months (June - August). In a study by Van der Colf (2011) the growth rate of the ryegrass component during winter and early spring was 33.2, 40.4 and 59.35 kg ha^{-1} day^{-1} for July, August and September, respectively. These growth rates coincide with the growth rates obtained during the current study; 34.6, 44.5 and 64.4 kg ha^{-1} day^{-1} for July, August and September, respectively. Pasture growth rate during September was twice that of the growth rate obtained during July. This is as a result of the increase in temperature, coupled with high rainfall levels (Weihing, 1970). Pasture growth rate will continue to increase into the summer months, reaching as high as 77 - 85 kg ha^{-1} day^{-1} (Dickinson *et al.*, 2004).

6.2 Rumen study

6.2.1 Rumen pH profiles

No difference in rumen pH was recorded between cows on treatments LC and HC (Figure 7). As a result of the high NDF content of the HF concentrate supplement the pH of the rumen would remain relatively stable, however due to the high level at which the HF concentrate supplement was fed to cows on treatment HC a drop in rumen pH was expected (Carruthers & Neil, 1997; Bargo *et al.*, 2002; Bargo *et al.*, 2003; Sayers *et al.*, 2003; Sairanen *et al.*, 2006). The fact that the high level of HF concentrate supplement feeding did not have an effect on the rumen pH is an indication of eNDF that was provided by the HF concentrate supplement. On this point alone the rumen health was not affected, but the time that the rumen spent below pH 6.2, 6.0 and 5.8 should also be taken into consideration when determining the overall health of the rumen.

According to Shriver *et al.* (1986) fibre digestion is optimised at pH 6.2 and below pH 6.0 the growth of certain bacterial species ceases (Hoover, 1986). According to Mould *et al.* (1983) and Hoover (1986) cyclic drops in the rumen pH profile, lasting for a short duration of time (one to two hours), do not have long lasting inhibitory effects on microbial activity. The rumen of cows on treatment HC did spend more time below pH 6.0 and pH 5.8 than the rumen of cows on treatment LC (Table 11), which would result in decreased microbial activity (Hoover, 1986; Shriver *et al.*,

1986). Evidence of lower activity in the rumen due to an extended period of time (more than one to two hours) spent below pH 6.0 and 5.8 can be seen in the data obtained from the *in sacco* Dacron bag study (6.2.3), as such rumen health was maintained where rumen activity was inhibited.

In the study by Lingnau (2011) the pH profile of cows receiving a low starch concentrate supplement was very similar to that obtained during the current study. Two decreases in the pH curve were seen after consumption of the HF concentrate supplement during the morning and afternoon milking sessions. This drop in pH was in response to the rapid degradation of the readily fermentable carbohydrates which were present in the HF concentrate supplement. The second decrease in the pH curve was more severe than the first. Very little time was allowed between the morning milking session and the afternoon milking session and the rumen pH was unable to stabilise before the intake of more HF concentrate supplement in the milking parlour. The highest pH values were recorded between 07:00 and 09:00, before the morning milking session. At this time the last intake of the HF concentrate supplement was more than 16 hours earlier, allowing ample time for the rumen pH to stabilise.

6.2.2 Rumen liquor samples

6.2.2.1 Volatile fatty acid profile

The acetate concentration of treatment LC at all three time intervals as well as the total daily acetate concentration was higher than that of treatment HC (Table 12, Table 17). The propionate concentration of treatment LC was lower than that for treatment HC, but only at the 13:30 time interval (Table 12, Table 17). In response to the higher acetate concentration of treatment LC, the acetate to propionate ratio of treatment LC at all three time intervals as well as the daily ratio was also higher than that of treatment HC (Table 13, Table 17). The increase in acetate concentration as well as the increase in the acetate to propionate ratio coincides with the increased milk fat content (5.1.1) which was obtained by cows on the LC treatment during the study (Kennelly & Glimm, 1998; Seymour *et al.*, 2005). The lower acetate to propionate ratio of the HC treatment could be explained by means of the pH data obtained (Figure 8) in relation to the specific VFA samples collected. A lower rumen pH will inhibit the activity of cellulolytic micro-organisms resulting in less acetate production and consequently a lower milk fat content. The longer time at which the rumen of cows on treatment HC spent below pH 6.0 and pH 5.8 (Table 11) also gives an indication that the activity of cellulolytic and fibrolytic micro-organisms was inhibited, resulting in lower acetate production.

Due to the high NDF content of the HF concentrate supplement an increase in the acetate to propionate ratio was expected for all three treatments in relation to any other commercially available high starch concentrate feed (McDonald *et al.*, 2000; Sairanen *et al.*, 2005). However in a study by Lingnau (2011) a concentrate supplement low in starch (high in fibre) did not show an

increase in the acetate to propionate ratio compared to a concentrate supplement high in starch (low in fibre) even though an increase in milk fat content was recorded. The acetate to propionate ratio obtained by Lingnau (2011) was 4.9 for cows receiving a high starch concentrate supplement and 4.99 for cows receiving a low starch concentrate supplement. The ratio for both of the concentrate supplement types is higher than the ratio obtained during this study (Table 17). Due to the higher ratio obtained by Lingnau (2011) a higher milk fat content is implied, this was however not the case. The lower ratios obtained in the current study still yielded a higher milk fat content than that of Lingnau (2011).

Butyrate concentration is highly positively correlated to milk yield but not to milk composition (Seymour *et al.*, 2005). No difference in the butyrate concentration of cows on treatment LC was found to that of cows on treatment HC. A decrease in butyric acid has been seen in response to lowering the starch content of a concentrate diet (Church, 1983; Lingnau, 2011). As such an overall decrease in butyrate concentration could be expected when feeding such a HF concentrate supplement, this was however not the case. Butyrate makes up a small % of the total VFA profile, only about 9-14 % (Church, 1983), as such changes are small and off less importance than changes in acetate or propionate concentration.

6.2.2.2 Ammonia nitrogen profile

No differences in NH_3-N concentration were found between cows on treatment LC and HC for all three time intervals (Table 15), as well as for the average daily NH_3-N (Table 17). According to Satter & Slyter (1974), Hoover (1986) and Khalili & Sairanen (2000) the lowest level of NH_3-N required for rumen micro-organisms to function is between 1 - 6 mg dL^{-1}. Satter & Slyter (1974) also state that extreme high NH_3-N concentrations, up to 80 mg dL^{-1}, 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). As such the NH_3-N recorded for cows on both treatment LC and HC was sufficient for maintaining rumen activity.

The trend of NH_3-N to increase after the morning milking session and again after the afternoon milking session in response to pasture intake, as described by Bargo *et al.* (2002), is also seen in the NH_3-N concentration data of the current study. Bargo *et al.* (2002) also states that the lowest NH_3-N levels are reached before the morning milking session in response to lower pasture intake; this was also found to be true in the current study. Ammonia nitrogen concentration does correspond to the pH data (6.2.2.3) obtained during this study, similarly to Lingnau (2011). A drop in rumen pH was experienced after the morning milking and again after the afternoon milking session resulting in a drop in rumen micro-organism activity. 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 (Figure 8). During the current study no differences were found between the rumen pH of cows on treatment LC and HC, as such the increase in NH_3-N after each milking session is as a result of a combination of events; pasture intake and a decrease in rumen pH due to concentrate supplementation intake.

6.2.2.3 pH

The pH values obtained using the hand held logger only differed at time interval 13:30, where cows on treatment HC had a lower pH than cows on treatment LC (Table 16). The highest pH was recorded at time interval 07:00 for both treatments. As no concentrate supplement was available to cows during the night and cows only consumed pasture the pH of the rumen was able to stabilise. The low pH value of the rumen of cows on treatment HC at time interval 13:30 is due to the high consumption of the HF concentrate supplement during the morning milking session. Cows on treatment HC had a lower pasture allowance (less peNDF) and were therefore unable to stabilise the pH before the next milking session.

The hand held logger was merely used to measure the pH of all the rumen samples so that a comparison between the VFA, NH_3-N and pH could be made. The pH profiles discussed in 6.2.1 provide a more accurate description of the rumen pH.

6.2.3 In sacco Dacron bag study

The extent of DM and NDF digestion of pasture was lower for cows on treatment HC compared to cows on treatment LC (Figure 9, Figure 10). When the pH data is taken into consideration it is clear to see that the longer time at which the rumen of cows on treatment HC spent below pH 6.0 and 5.8 had a negative effect on the activity of cellulolytic and fibrolytic bacteria (Mould *et al.*, 1983; Hoover, 1986). Lowered microbial activity in the rumen would then result in a decrease in DM and NDF digestion of pasture. Cows of treatment HC were able to digest pasture efficiently so as to maintain a high milk production, although milk production could possibly have been improved if rumen pH was better maintained.

Lingnau (2011) found that feeding a low starch concentrate supplement to cows on pasture did not improve the digestibility of pasture compared to feeding a high starch concentrate supplement. Therefore, the higher NDF of the HF concentrate supplement used in the current study could not be expected to improve the cellulolytic and fibrolytic micro-organism activity substantially. Berzaghi *et al.* (1996) also found that feeding concentrate supplement lowered the digestibility of pasture compared to if pasture was the only feed source. Due to this decrease in digestibility of pasture in response to concentrate supplement feeding, a decrease in pasture digestibility as the HF concentrate supplement level was increased from treatment LC to HC was expected.

6.3 Regression

Throughout the study period a regression was cut on the pasture which was grazed by all three treatments. According to Sanderson *et al.* (2001) the inaccuracy of the RPM in estimating pasture yield is linked to the linear regression equations which are used; linear regression equations designed for a specific area, a specific pasture type and a specific season should be used to increase the accuracy of estimating pasture yield. The linear regression equation which was used to allocate cows to pasture was obtained from Van der Colf (2011) (4.2.2). The study by Van der Colf (2011) was carried out on a similar area on the Outeniqua Research farm as was used during the current study as well as during the same season; this linear regression equation was the most accurate one available to use during the current study.

The regression equation which was obtained during the current study (Figure 11) was used to estimate pasture intake after the study was completed, this linear regression equation helped to increase the accuracy of estimating pasture intake. Even though the linear regression equation improved the accuracy of estimating pasture intake it still remains an estimation. The optimum post-grazing height of 10 - 12 RPM remains the same regardless of which linear regression equation is used. As such monitoring post-grazing height remains an important management tool. Unfortunately for pasture based research intake is required and developing a linear regression equation remains crucial.

6.4 Stocking rate

The farmlet size comprises the area which was assigned to cows on each treatment during the first cycle (Table 18) as described in 4.2.2. During the second and third cycle the same camps were grazed by each treatment again, as such the farmlet size remained constant during the study period for all three treatments. It is clear to see that cows on treatment LC had the largest farmlet size. This corresponds to the higher pasture allowance and the larger number of camps which were assigned to treatment LC. Cows on treatment HC had the smallest farmlet size due to the very high pasture allowance. Cows on treatment LC had fewer grazing days per cycle due to the higher pasture allowance. The different grazing days per cycle resulted in the treatments not grazing camps close to each other; they became out of sync. As such cows on treatment LC were at the second last camp (camp 22) at the completion of the study and cows on treatment MC (camp 17) and HC (camp 18) were only at the third last camp at the completion of the study (Figure 4).

Stocking rate was calculated using the number of cows on each treatment and the farmlet size assigned to each treatment. As the grazing days were calculated per cycle, the stocking rate also applies to each cycle. Calculating stocking rate according to each month would have shown the relationship between stocking rate and pasture growth rate (Clark & Kanneganti, 1998; Tainton,

2000), but the varying lengths of the grazing cycles prevented this. A grazing cycle was on average slightly longer than a month. Therefore, only the average stocking rate over the whole period is provided. Pasture allowance remained the same throughout the study the only variable factor was the growth rate of the pasture, which ultimately had an effect on the stocking rate.

As one of the aims of the study was to determine how much pasture could be saved during the winter months when pasture intake was restricted, the % pasture saved by cows on treatment MC and HC was calculated in relation to treatment LC. The total area grazed during the study period (sum of all three grazing cycles) by each treatment was used to calculate % pasture saved. The strategy followed by cows on treatment LC is typical of the summer months when pasture growth rates are high and enough roughage is available. It was found that when following the HC treatment strategy 36.7 % less pasture was used than during the summer months or when following the LC treatment strategy. Similarly, when following the MC treatment strategy 22.3 % less pasture was used than during the summer months or when following the LC treatment strategy. At the commencement of the study it was thought that cows on treatment HC would utilise pasture in a 1:2 ratio with cows on treatment LC, where cows on treatment HC would utilise half of the pasture utilised by cows on treatment HC, however cows on treatment HC consumed pasture in a 1:1.2 ratio with cows on treatment LC. The disparity can be explained by looking at the estimated pasture intake of cows on treatment LC and HC (Table 10). Cows on treatment LC only consumed 8.66 kg DM pasture, where they were allocated 10 kg DM according to the treatment specifications and cows on treatment HC consumed 5.02 kg DM pasture where they were allocated 5 kg DM according to treatment specifications. The lower pasture intake of cows on treatment LC consequently resulted in the total area that was grazed being smaller than would be expected if the treatment specifications were adhered to with regards to pasture intake.

It was also found that as the stocking rate increased, pasture utilisation improved. Cows on treatment LC (stocking rate = 5.07 cows ha^{-1} $cycle^{-1}$) had a 5.44 kg DM pasture gap between pasture allocation and pasture intake, cows on treatment MC (stocking rate = 6.07 cows ha^{-1} $cycle^{-1}$) had a 3.76 kg DM pasture gap and cows on treatment HC (stocking rate = 7.64 cows ha^{-1} $cycle^{-1}$) only had a 3.23 kg DM disparity. This coincides with the findings of Vazquez & Smith (2000), Bargo *et al.* (2003), Tozer *et al.* (2004) and McEvoy *et al.* (2008) where lower pasture allowance and higher stocking rates lower substitution rate and improve pasture utilisation.

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7 Economic evaluation

The economic evaluation was calculated on a herd size of 300 Jersey cows, which is the average herd size of dairy farms in the Southern Cape of South Africa. Milk production for the three treatments shown in Table 19 depicts the actual milk production obtained during the study. The milk production for the grass silage and lucerne hay strategies was estimated and does not reflect specific values obtained during the winter months of 2011. The milk price for the three treatments was received from Nestlé and the influence of milk fat content on the milk price is evident; higher milk fat content results in a higher milk price. The milk price for the grass silage and lucerne hay strategies as shown in Table 19 reflects the actual milk price which was obtained by the large herd of the Outeniqua Research farm during the winter months of 2011. The HF concentrate supplement price of the three treatments was obtained from NOVA feeds and includes the cost of the premix as well. The price of the concentrate supplement provided to cows on the grass silage and lucerne hay strategies reflects the actual cost of the concentrate supplement fed to the large herd of the Outeniqua Research farm during the winter months of 2011. The supplement prices for the grass silage and lucerne hay are estimated values that can vary over a large price range. Producing grass silage at a cost higher than R 1300 per ton (as is) will not prove economically viable under any circumstances. The lucerne hay price also varies a lot and can increase to as much as R2400 per ton (as is). The price of 1 kg pasture (as is) was obtained from the Outeniqua Research Farm during the winter months of 2011. The net daily and monthly profit only depicts the margin above feed costs and does not take any labour, machinery or any other farm related costs into consideration.

Table 19 Profit as calculated for margin above feed costs for all three high fibre concentrate supplement treatments as well as estimated for two current strategies to overcoming winter roughage shortages

Parameter	Treatment			Grass silage + concentrate + pasture	Lucerne hay + concentrate + pasture
	LC	MC	HC		
Milk yield (kg cow^{-1} day^{-1})	16.18	17.25	18.12	16	16
Milk yield (kg herd^{-1*} day^{-1})	4854	5175	5436	4800	4800
Milk fat content (%)	4.92	4.96	4.58	-	-
Milk price (R** L^{-1})	3.29	3.31	3.21	3.22	3.22
Milk income (R herd^{-1} day^{-1})	15970	17129	17450	15456	15456
Concentrate price (R ton^{-1})	2570	2570	2570	3060	3060
Concentrate inclusion level (kg as is)	4	7	10	5	5
Concentrate price (R cow^{-1} day^{-1})	10.28	17.99	25.7	15.3	15.3
Concentrate price (R herd^{-1} day^{-1})	3084	5397	7710	4590	4590
Supplement price (R ton^{-1})	0	0	0	1300	2000
Supplement inclusion level*** (kg DM)	0	0	0	5	5
Supplement price (R cow^{-1} day^{-1})	0	0	0	6.5	10
Supplement price (R herd^{-1} day^{-1})	0	0	0	1950	3000
Pasture price (R kg^{-1})	1	1	1	1	1
Pasture allowance (kg DM)	10	7	5	5	5
Pasture price (R cow^{-1} day^{-1})	10	7	5	5	5
Pasture price (R herd^{-1} day^{-1})	3000	2100	1500	1500	1500
Total feed input cost (R herd^{-1} day^{-1})	6084	7497	9210	8040	9090
Daily margin over feed costs (R herd^{-1} day^{-1})	9886	9632	8240	7416	6366
Monthly margin over feed cost (R herd^{-1} month^{-1})	296570	288968	247187	222480	190980

* Herd = 300 cows which is the average herd size in the Southern Cape of South Africa
** R - South African currency, rand
*** Supplement inclusion level - does not take wastage of 10 - 20 % into consideration

As the study only included the LC treatment, MC treatment and HC treatment the results obtained cannot be compared on a statistical or scientifically sound level to the grass silage and lucerne hay strategies. However from a practical view point it is of the utmost importance to know whether the HF concentrate supplement and pasture restriction is economically viable or not compared to current strategies.

The net monthly profit of treatment HC is lower than that for treatment LC and treatment MC.

This is due to a combination of factors. Cows on treatment HC had a lower milk fat content and received a lower milk price accordingly. Cows on treatment HC also consumed more than twice the amount of HF concentrate supplement compared to cows on treatment LC, and as pasture is always the cheapest feed source, this contributed to the lower net monthly profit. However cows on treatment HC did produce more milk than cows on treatment LC and this helped to lower the difference in net monthly profit. The strategy of treatment LC represents the ideal situation and will not be obtainable during the winter months due to pasture shortages. As a solution to overcoming pasture shortages the strategy of treatment HC is economically viable.

When the HC treatment strategy is compared to the grass silage and lucerne hay strategies there is a definite increase in net monthly profit. The price of lucerne hay and the cost of implements for ensiling will all influence the net monthly profit and will determine whether the HC treatment strategy is more economically viable than the grass silage and lucerne hay strategies. One factor that will remain in the favour of the HC treatment strategy is the lower cost of a HF based concentrate supplement compared to a high starch based concentrate supplement.

8 Conclusion

Cows consuming a higher level of a high fibre (HF) concentrate supplement and less pasture were able to maintain a higher level of milk production. Milk composition was slightly compromised at such high levels of concentrate feeding; milk fat and protein content decreased. The decrease in milk fat content is reflected in the rumen study results. High levels of concentrate supplement feeding resulted in the rumen pH spending a longer time below pH 6.0 and pH 5.8, lowering the activity of the rumen micro-organisms. Lowered rumen activity is evident when the extent of dry matter (DM) and neutral detergent fibre (NDF) disappearance is taken into account; higher levels of a HF concentrate supplement negatively impacted the degradation of pasture in the rumen. Lower rumen activity is also evident in the volatile fatty acids (VFA) samples collected, where higher levels of a HF concentrate supplement resulted in lowered acetate production, the effect of which can be clearly seen in the lower milk fat content.

During the winter months the pasture had a very low content of structural components such as NDF and acid detergent fibre (ADF) and was highly digestible, as such pasture provided little in the way of effective NDF (eNDF) or physically effective NDF (peNDF). The HF concentrate supplement which was used was very high in NDF and low in readily fermentable carbohydrates compared to conventional concentrate supplements used in the dairy industry. When the high milk fat content of cows receiving the HF concentrate supplement is considered, the concentrate supplement provided sufficient eNDF. However, the HF concentrate supplement provided low levels of peNDF. This is evident as the rumen activity could not be maintained when high levels of the HF concentrate supplement were fed and pasture intake was restricted. There was no occurrence of clinical acidosis, nor did any cows develop mastitis or foot problems. Therefore, rumen activity was inhibited but rumen health was not compromised. There are no clear guidelines to eNDF and peNDF requirements for cows on a pasture based system. In this study it was found that allowing adequate adaptation enables cows to sustain high milk production and maintain rumen health even when seemingly low levels of peNDF are supplied. Further investigation into the specific NDF requirements for cows grazing pasture is required.

The focus of the study was on finding an alternative, practically applicable way for farmers to manage roughage shortages during the winter months. Through feeding higher levels of a HF concentrate supplement the requirement for pasture was lowered and pasture intake could be greatly restricted. Restricting pasture intake required cows to graze at higher stocking rates with a much lowered pasture allowance. High stocking rates and lowered pasture allowance ensured efficient grazing of pasture and good pasture re-growth. Restricting pasture intake while feeding higher levels of a HF concentrate supplement will enable farmers to maintain the full dairy herd throughout the winter months without having to reduce the herd size, without buying in additional

roughage sources and without making provisional silage.

Feeding higher levels of a HF concentrate supplement in the milking parlour did require extra time, to that allocated for milking. Cows did however adapt quickly after which cows were able to consume all the feed within the allotted time. Starting adaptation two weeks before roughage shortages become a major problem should make the transition such that no extra time is required in the milking parlour.

With the scenario experienced on the Outeniqua Research farm during the winter months of 2011 this strategy did prove to have substantial economical benefits. The economical implications are highly variable and depend on many factors such as price of lucerne hay, availability of surplus pasture for ensiling and availability of implements. Ensiling surplus pasture is considered the most economical strategy, although ensuring surplus pasture for ensiling means that the herd size has to be restricted and the entire pasture area is not used for grazing. By feeding high levels of a HF concentrate supplement and restricting pasture intake there is no need for silage, as such the size of the dairy herd can be increased and all available pasture utilised for grazing throughout the year.

9 Critical evaluation

Time lapse between morning and afternoon milking session: Ideally the two milking sessions should be spread out evenly throughout the day. Due to practical issues surrounding the ongoing farm processes and the simultaneous integration of the trial cows the milking times for cow in the current study were not ideal. Only six hours separated the morning milking session from the afternoon milking session, where as 18 hours separated the afternoon milking session from the next day's morning session. Splitting the feeding and milking times evenly throughout the day should result in a more uniform utilisation of nutrients and could also help to improve intake.

Late commencement of the trial: The aim of the study was very specifically targeted at overcoming roughage shortages during the winter months. Temperatures begin to drop in June and this month marks the beginning of winter. Due to logistical problems the trial only commenced in July. During September the temperatures start to increase and a large response in growth rate of ryegrass pasture is seen. As such the trial should ideally have been carried out during the months of June to October and not July to September. The increase in growth rate of ryegrass pasture during September resulted in an oversupply of pasture on the research grazing area and pasture was not used to its full potential. High stocking rates and pasture restrictions were maintained throughout the study regardless of pasture growth rate.

Allocation of pasture: It was difficult to determine the amount of pasture which was actually saved. As the area grazed during the first cycle was set before cows were adapted to the high level of concentrate supplement and before the student had a secure handle on pasture measuring and DM prediction, 50 % of the area was not saved, as was expected when pasture allocation is considered. This problem could have been avoided by dividing the area available for the study into three sections with different areas, representative of the relevant ratios in which pasture would be consumed. This would have allowed for a fixed area related to pasture intake as well as allowing for a fixed grazing cycle. In this scenario it could then be argued that pasture quality could play a role in production as animals are grazing three different areas, this can be avoided by analysing pasture before commencement to ensure no differences.

Adaptation period and pasture allocation: A three week adaptation period was allowed before the study commenced. The allocation of camps started at the commencement of the study while cows were still adapting and pasture allocation did not strictly adhere to treatment specifications. At least the first week of this adaptation should have taken place on a separate area of pasture which was not used for the study; this would have helped to improve the allocation of pasture and prevented

the treatments becoming out of sync.

Milk sampling: The milking machine was not always able to siphon off the correct amount of milk from each cow. There was a lot of variation in milk sampling data and various sampling periods were repeated and previous data deleted. The technique and organisation improved with time, but maintenance of the milking machine and sampling components should be a priority on any dairy farm.

Compare alternative solutions followed during winter months: As the threshold for feeding concentrate supplements and restricting pasture intake were only established in this study it was not possible to include any other treatments pertaining to alternative over wintering strategies. Due to this the success of the HF concentrate supplement in relation to feeding lucerne hay or silage in regards to production, rumen activity, rumen health and economic viability could only be speculated. Future studies should be based on comparing the three strategies.

Include more buffers: The effectiveness of buffers in maintaining the rumen pH of cows on pasture is not yet fully understood. There might be some merit in including a larger percentage of buffers in the diet, especially when feeding such high levels of the high fibre concentrate supplement, where pH activity was inhibited.

Lower inclusion level of wheat bran: Wheat bran was included at such high levels in prevention of acidosis. It might be possible to replace 5 - 10 % of the wheat bran with ground maize without developing acidosis, at the same time milk production could improve. The higher inclusion level of maize will have a marked effect on the price of the concentrate supplement and the economic viability of it should be considered.

10 Appendix

Table 20 Blocking of cows on the LC treatment, according to milk yield (kg), days in milk (DIM) and lactation number

Block	Cow number	Milk yield (kg)	DIM	Lactation number	Fat (%)	FCM
1	MARL 82	17.6	49	5	5.33	21.14
2	SYMB 62	19.0	46	9	5.05	22.04
3	MART 162	16.4	36	5	5.63	20.44
4	MARL 99	15.9	35	4	5.12	18.52
5	MART 170	15.4	74	4	3.92	15.18
6	BELLA 165	15.1	108	2	5.19	17.78
7	ALET 106	14.4	165	5	5.63	17.89
8	GRET 31	13.6	207	7	5.58	16.88
9	BELL 149	14.6	156	4	5.14	17.13
10	IDA 38	14.6	70	3	5.73	18.34
11	BLON 76	13.4	135	4	5.5	16.43
12	MARL 92	15.1	24	4	5.18	17.76
13	JAPN 65	11.7	160	6	5.91	15.00
14	MART 186	12.7	169	3	5.65	15.89
15	STELL 18	12.9	196	2	5.49	15.79
16	MARL 75	12.7	140	5	5.17	14.92

Table 21 Blocking of cows on the MC treatment, according to milk yield (kg), days in milk (DIM) and lactation number

Block	Cow number	Milk yield (kg)	DIM	Lactation number	Fat (%)	FCM
1	ALET 107	16.8	39	5	5.08	19.51
2	SYMB 67	19.6	29	6	3.7	18.67
3	JAPN 76	16.3	38	5	5.61	20.26
4	BELLA 163	16.4	47	3	4.56	17.77
5	DORA 140	16.4	52	3	4.25	17.05
6	MART 191	15.3	70	2	5.38	18.52
7	ELIZE 89	14.4	151	4	5.07	16.73
8	BLON 43	13.6	131	9	4.18	13.97
9	BABS 32	14.2	132	3	5.31	17.04
10	MARL 103	12.8	99	2	5.34	15.40
11	MARL 94	12.7	177	5	5.9	16.36
12	LAUR 41	14.7	41	4	4.99	16.94
13	MART 141	11.0	198	7	5.9	14.10
14	BELLA 167	11.7	119	2	5.68	14.59
15	GERL 21	12.6	181	6	4.64	13.76
16	MARL 85	12.7	108	4	5.05	14.75

Table 22 Blocking of cows on the HC treatment, according to milk yield (kg), days in milk (DIM) and lactation number

Block	Cow number	Milk yield (kg)	DIM	Lactation number	Fat (%)	FCM
1	SYMB 65	19.9	41	6	5.85	25.38
2	DONN 6	18.3	50	8	3.59	17.17
3	BLON 64	19.0	36	6	4.21	19.65
4	LORN 16	15.9	28	4	5.62	19.72
5	MART 201	15.6	51	2	4.89	17.69
6	BELLA 164	14.7	50	3	4.73	16.29
7	BELL146	13.7	159	4	5.23	16.22
8	MAGD 81	15.1	112	6	5.58	18.72
9	DORA 149	14.1	203	2	5.08	16.36
10	FIRE 54	13.5	62	3	6.37	18.31
11	GRET 52	14.4	143	3	4.74	16.00
12	ALET 113	14.3	13	4	4.66	15.75
13	JAPN 91	12.6	207	4	5.95	16.25
14	MAGD 86	11.2	192	3	6.1	14.78
15	BELLA 160	13.2	195	3	5.85	16.87
16	JAPN 62	13.1	63	7	5.39	15.85

Table 23 Measuring and allocation of pasture to cows on each treatment during cycle one

Camp	Lane	Size (ha)	Treatment	RPM mean before	Allocated grazings	Pasture allocated/ day/ cow	RPM mean after	Intake/ cow/ day	Date on	Time on	Date off	Time off
1	a	0.172	LC		3		11.90		05*07	pm	07*07	am
1	b	0.172	LC	24.72	4	8.82	9.96	5.78	07*07	am	09*07	am
2	a	0.177	MC		3		11.46		05*07	pm	07*07	am
2	b	0.174	MC	25.42	4	9.20	9.76	6.20	07*07	am	11*07	am
3	a	0.194	HC		3		13.28		05*07	pm	07*07	am
3	b	0.183	HC	31.46	6	8.13	9.72	6.04	07*07	am	10*07	am
4	a	0.204	MC	29.52	4	12.69	11.95	8.16	09*07	am	11*07	am
4	b	0.202	MC	29.89	4	12.73	10.38	8.97	11*07	am	13*07	pm
5	a	0.197	LC	25.12	4	10.28	11.46	6.13	09*07	am	11*07	am
5	b	0.201	LC	30.93	4	13.15	8.92	10.07	11*07	am	13*07	am
6	a	0.19	HC	26.95	5	8.56	9.44	6.06	10*07	am	12*07	pm
6	b	0.193	HC	33.51	5	11.00	10.21	8.19	12*07	pm	15*07	am
7	a	0.183	LC	30.50	4	11.79	10.15	8.48	13*07	am	15*07	am
7	b	0.187	LC	33.68	4	13.40	10.09	10.04	15*07	am	17*07	am
8	a	0.176	MC	27.73	4	10.23	11.10	6.66	13*07	am	15*07	am
8	b	0.18	MC	27.64	5	8.34	9.90	5.82	15*07	am	17*07	pm
9	a	0.19	HC	27.02	6	7.16	10.77	4.69	15*07	am	18*07	am
9	b	0.173	HC	31.27	7	6.54	10.02	4.78	18*07	am	21*07	pm
10	a	0.184	LC	38.02	4	15.00	13.49	10.28	17*07	am	19*07	am
10	b	0.189	LC	31.82	4	12.74	13.21	8.01	19*07	am	21*07	am
11	a	0.174	MC	32.23	5	9.52	13.06	6.07	17*07	pm	20*07	am
11	b	0.177	MC	30.99	5	9.28	11.44	6.30	20*07	am	22*07	pm
12	a	0.17	LC	27.73	3	13.17	12.60	7.81	21*07	am	22*07	pm
12	b	0.17	LC	28.64	3	13.64	15.45	6.81	22*07	pm	24*07	am
13	a	0.169	HC	30.77	6	7.33	13.34	4.47	21*07	pm	24*07	pm
13	b	0.17	HC	30.65	6	7.34	9.83	5.37	24*07	pm	27*07	pm
14	a	0.162	MC	29.37	4	10.02	13.93	5.69	22*07	pm	24*07	pm
14	b	0.167	MC	31.50	5	8.91	9.03	6.83	24*07	pm	27*07	am
15	a	0.222	LC	27.69	4	12.88	13.40	7.22	24*07	am	26*07	am
16	a	0.119	LC		2	0.00	13.30		26*07	am	27*07	am
16	b	0.187	LC	25.71	3	13.34	12.57	7.46	27*07	am	28*07	pm
17	a	0.188	MC	26.98	3	14.14	11.03	9.10	27*07	am	28*07	pm
17	b	0.188	MC	27.18	4	10.69	12.65	6.22	28*07	pm	30*07	pm
18	a	0.188	HC	22.31	3	11.47	14.20	4.63	27*07	pm	29*07	am
18	b	0.188	HC	14.18	2	10.25	10.30	3.32	29*07	am	30*07	am
19	a	0.188	LC	22.49	2	17.37	11.78	9.17	28*07	pm	29*07	pm
19	b	0.188	LC	25.67	3	13.39	12.87	7.30	29*07	pm	31*07	am
20	a	0.188	HC	22.85	5	7.07	9.53	4.56	30*07	am	01*08	pm
20	b	0.188	HC	21.85	4	8.41	10.90	4.69	01*08	pm	03*08	pm
21	a	0.188	MC	25.85	4	10.12	10.72	6.48	30*07	pm	01*08	pm
21	b	0.188	MC	23.21	3	11.99	10.51	7.25	01*08	pm	03*08	am
22	a	0.187	LC	22.94	2	17.66	11.52	9.72	31*07	am	01*08	am
22	b	0.188	LC	25.97	3	13.56	11.56	8.22	01*08	am	02*08	pm
23	a	0.187	LC	26.29	3	13.67	10.50	8.96	02*08	pm	04*08	am
23	b	0.186	LC	30.04	3	15.72	10.79	10.87	04*08	am	05*08	pm
24	a	0.187	MC	20.11	3	10.16	9.88	5.81	03*08	am	06*08	am
24	b	0.186	MC	24.35	3	12.50	9.42	8.43	04*08	pm	06*08	am

Table 24 Measuring and allocation of pasture to cows on each treatment during cycle two

Camp	Lane	Size (ha)	Treatment group	RPM mean before	Allocated grazings	Pasture allocated/ day/ cow	RPM mean after	Intake/ cow/ day	Date	Time	Date	Time
1	a	0.172	LC	19.19	2	13.30	10.21	7.03	05*08	pm	06*08	pm
1	b	0.172	LC	20.48	2	14.31	8.7	9.23	06*08	pm	08*08	am
2	a	0.177	MC	22.05	3	10.66	10.08	6.43	06*08	am	07*08	pm
2	b	0.174	MC	22.05	3	10.48	10.72	5.98	07*08	pm	07*08	am
3	a	0.194	HC	22.28	5	7.09	9.43	4.54	03*08	pm	06*08	am
3	b	0.183	HC	18.69	3	9.16	11	4.27	06*08	am	07*08	pm
4	a	0.204	MC	23.89	3	13.43	12.54	7.03	09*08	am	10*08	pm
4	b	0.202	MC	24.56	4	10.28	10.53	6.45	10*08	pm	12*08	pm
5	a	0.197	LC	20.78	2	16.66	11.34	8.47	07*08	pm	08*08	pm
5	b	0.201	LC	23.20	3	12.81	9.11	8.60	08*08	pm	10*08	am
6	a	0.19	HC	20.47	4	7.90	9.24	4.86	07*08	pm	09*08	pm
6	b	0.193	HC	21.57	4	8.51	10.4	4.91	09*08	pm	11*08	pm
7	a	0.183	LC	22.8	2	17.16	10.43	10.31	10*08	am	11*08	am
7	b	0.187	LC	24.95	3	12.91	9.56	8.74	10*08	am	11*08	am
8	a	0.176	MC	24.73	3	12.03	10.45	7.63	12*08	pm	14*08	am
8	b	0.18	MC	21.99	3	10.81	8.69	7.27	14*08	am	15*08	pm
9	a	0.19	HC	22.19	5	6.92	9.75	4.30	11*08	pm	14*08	am
9	b	0.173	HC	23.79	5	6.80	7.23	5.22	14*08	am	16*08	pm
10	a	0.184	LC	23.79	3	12.06	10.67	7.33	12*08	pm	14*08	am
10	b	0.189	LC	22.19	3	11.47	10.75	6.56	14*08	am	15*08	pm
11	a	0.174	MC	23.06	3	11.02	9.28	7.28	15*08	pm	17*08	am
11	b	0.177	MC	20.48	3	9.82	10.19	5.53	17*08	am	18*08	pm
12	a	0.17	LC	22.45	2	15.67	12.3	7.86	15*08	pm	16*08	pm
12	b	0.17	LC	23.01	2	16.11	11.05	9.26	16*08	pm	17*08	pm
13	a	0.169	HC	19.68	3	8.97	10.53	4.69	16*08	pm	18*08	am
13	b	0.17	HC	15.99	2	10.67	9.62	4.93	18*08	am	19*08	am
14	a	0.162	MC	23.09	3	10.27	10.24	6.32	18*08	pm	20*08	am
14	b	0.167	MC	16.45	2	10.83	8.57	5.99	20*08	am	21*08	am
15	a	0.222	LC	21.34	3	12.90	10.09	7.58	17*08	pm	19*08	am
15	b	0.178	HC	26.98	6	8.37	16.2	3.64	27*08	pm	30*08	pm
16	a	0.208	LC	28.74	3	16.75	12.57	10.21	19*08	am	20*08	pm
16	b	0.187	LC	24.18	3	12.47	10.37	7.84	20*08	pm	22*08	am
17	a	0.188	MC	27.65	4	10.89	13.3	6.14	21*08	am	23*08	pm
17	b	0.188	MC	24.46	4	9.53	12.58	6.36	23*08	pm	25*08	am
18	a	0.188	HC	20.65	4	7.90	11.8	3.79	19*08	am	21*08	am
18	b	0.188	HC	21.38	4	8.21	11.8	4.10	21*08	am	23*08	am
19	a	0.188	LC	23.8	3	15.41	12.95	7.74	22*08	am	23*08	pm
19	b	0.188	LC	22.83	3	14.71	11.95	7.76	23*08	pm	25*08	am
20	a	0.188	HC	18.65	4	8.28	9.33	4.99	23*08	am	25*08	am
20	b	0.188	HC	21.52	5	7.78	11.52	4.28	25*08	am	27*08	pm
21	a	0.188	MC	23.53	4	11.41	11.23	6.58	25*08	am	27*08	am
21	b	0.188	MC	21.79	4	10.48	11.27	5.63	27*08	am	29*08	am
22	a	0.187	LC	23.05	3	14.79	12.57	7.44	25*08	am	26*08	pm
22	b	0.188	LC	23.89	3	15.47	12.72	7.97	26*08	pm	28*08	am
23	a	0.187	LC	25.38	3	16.45	13.58	8.37	28*08	am	29*08	pm
23	b	0.186	LC	25.08	3	16.15	12.43	8.93	30*08	am	31*08	am
24	a	0.187	MC	26.98	5	10.55	10.92	6.84	29*08	am	31*08	pm
24	b	0.186	MC	24.46	4	11.78	11.31	6.96	31*08	am	02*09	pm

Table 25 Measuring and allocation of pasture to cows on each treatment during cycle three

Camp	Lane	Size (ha)	Treatment group	RPM mean before	Allocated grazings	Pasture allocated/ day/ cow	RPM mean after	Intake/ cow/ day	Date	Time	Date	Time
1	a	0.172	LC	24.46	3	14.53	14.26	6.66	31*08	am	01*09	pm
1	b	0.172	LC	24.2	3	14.36	9.51	9.59	01*09	pm	03*09	am
2	a	0.177	MC	29.7	5	11.08	10.54	7.72	02*09	pm	05*09	am
2	b	0.174	MC	24.41	4	11.00	11.66	6.31	05*09	am	07*09	am
3	a	0.194	HC	21.48	5	8.51	11.46	4.43	30*08	pm	02*09	am
3	b	0.183	HC	23.95	6	7.55	9.65	4.96	02*09	am	05*09	am
4	a	0.204	MC	26.43	5	11.25	11.48	6.94	07*09	am	0*09	pm
4	b	0.202	MC	28.62	6	10.12	9.38	7.37	09*09	pm	12*09	pm
5	a	0.197	LC	28.4	4	14.69	9.67	10.50	03*09	am	05*09	am
5	b	0.201	LC	24.33	3	16.88	12.53	9.00	05*09	am	06*09	pm
6	a	0.19	HC	22.71	6	7.39	8.93	4.97	05*09	am	08*09	am
6	b	0.193	HC	28.48	7	8.25	9.38	5.99	08*09	am	11*09	pm
7	a	0.183	LC	25.43	3	16.13	10.23	10.55	06*09	pm	08*09	am
7	b	0.187	LC	30.41	4	15.01	9.94	10.89	08*09	am	10*09	am
8	a	0.176	MC	33.27	6	10.37	10.18	7.71	12*09	pm	15*09	pm
8	b	0.18	MC	35.22	7	9.66	8.78	7.74	15*09	pm	19*09	am
9	a	0.19	HC	34.63	8	8.77	10.6	6.50	11*09	pm	15*09	pm
9	b	0.173	HC	33.64	8	7.74	10.96	5.58	15*09	pm	19*09	pm
10	a	0.184	LC	32.28	5	12.60	12.29	8.37	10*09	am	12*09	pm
10	b	0.189	LC	31.86	5	12.76	10.41	9.23	12*09	pm	15*09	am
11	a	0.174	MC	36.67	7	9.75	10.56	7.39	19*09	am	22*09	pm
11	b	0.177	MC	38.45	7	10.43	9.43	8.35	22*09	pm	26*09	am
12	a	0.17	LC	41.76	6	12.76	11.44	9.78	15*09	am	18*09	am
12	b	0.17	LC	34.99	5	12.69	12.9	8.55	18*09	am	20*09	pm
13	a	0.169	HC	41	9	8.29	10.88	6.44	19*09	pm	24*09	am
13	b	0.17	HC	37.39	9	7.57	10.22	5.84	24*09	am	28*09	pm
14	a	0.162	MC	38.74	7	9.63	10.8	7.36	26*09	am	29*09	pm
14	b	0.167	MC	42.07	7	10.83	8.48	9.12	29*09	pm	03*10	am
15	a	0.222	LC	36.74	6	14.55	12.69	10.13	20*09	pm	23*09	pm
16	a	0.208	LC	35.18	6	13.01	10.31	9.81	23*09	pm	26*09	pm
16	b	0.187	LC	35.25	5	14.07	12	9.90	26*09	pm	29*09	am
17	a	0.1175	MC	41.29	5	10.46			03*10	am	05*10	am
18	a	0.188	HC	39.54	11	7.26	9.83	5.78	28*09	pm	04*10	am
18	b	0.05875	HC	43.61	3	9.23			04*10	am	05*10	am
19	a	0.188	LC	33.64	5	13.45	13.02	8.82	29*09	am	01*10	pm
19	b	0.188	LC	34.13	5	13.66	10.13	10.27	01*10	pm	04*10	am
22	a	0.1122	LC	36.67	3	14.67			04*10	am	05*10	am