NUTRITIVE VALUE OF TALL FESCUE (*Festuca arundinacea*) ESTABLISHED ON REHABILITATED MINELAND FOR GRAZING CATTLE

by

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DECLARATION

I, Marjorie Janse van Rensburg, declare that the dissertation, which I hereby submit for the degree MSc (Agric) Animal Science: Nutrition Science at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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LIST OF ABREVIATIONS

a	-	rapidly soluble fraction
ADF	-	Acid detergent fiber
ADG	-	Average daily gain
b	-	Degradable insoluble fraction
B	-	Boron
BW	-	Body weight
c	-	degradation rate constant of the b fraction
Ca	-	Calcium
$CaCl_2$	-	Calcium Chloride
Cl	-	Chloride
CNS	-	Central nervous system
Cu	-	Copper
CO_3^{2-}	-	Carbonate ion
CP	-	Crude protein
CRD	-	Controlled-release device
DM	-	Dry matter
DMD	-	Dry matter digestibility
ED	-	extent of ruminal DM degradation
Fe	-	Iron
GC	-	Gas chromatography
HN	-	High initial N
HS	-	High stocking rate
IVDMD	-	*In vitro* dry matter digestibility
IVOMD	-	*In vitro* organic matter digestibility
K	-	Potassium
LN	-	Low initial N
LS	-	Low stocking rate
ME	-	Metabolisable energy
Mg	-	Magnesium
$MgCl_2$	-	Magnesium chloride
Mn	-	Manganese
MS		Medium stocking rate
Na	-	Sodium
NaCl	-	Sodium chloride

N	-	Nitrogen
NDF	-	Neutral detergent fiber
NH_3-N	-	Ammonia-nitrogen
NH_4^+	-	Ammonium ion
NO_3^-	-	Nitrate ion
OM	-	Organic matter
P	-	Phosphorous
S	-	Sulphur
SEM	-	Standard error of the mean
t	-	Metric ton
VFA	-	Volatile fatty acids
WSC	-	Water soluble carbohydrates
Zn	-	Zinc

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SUMMARY

Sustainable animal production on pasture planted on rehabilitated mine land will only be possible if the optimal stocking rate for animal and pasture production is determined. A grazing trial was conducted on tall fescue, established on rehabilitated mine land and irrigated with mine waste water. The aims of this study were to quantify: a) animal performance and nutritive value at different levels of nitrogen (N) fertilization during pasture establishment, and b) intake, animal performance (defined as average daily gain; ADG) and nutritive value when different stocking rates were applied. This study was done during two seasons: season one in winter (6 June -16 July 2008) and season two in spring (28 Aug – 6 Nov 2008). In terms of post mining land use this study supplied valuable information on potential livestock production.

The higher level of N fertilization applied during the winter of 2007 at pasture establishment resulted in a significantly ($P < 0.05$) higher crude protein (CP) concentration a year later compared to the lower levels of N fertilization. During the winter grazing season the pasture contained an average of 83.4 g CP kg^{-1} dry matter (DM), 601.9 g NDF kg^{-1} DM, 6.2 g Ca kg^{-1} DM and 1.7 g P kg^{-1} DM, the average *in vitro* organic matter digestibility (IVOMD) was 642.2 g kg^{-1} OM and the average leaf: stem ratio was 88:12. The ADG of crossbred weaner calves grazing the low N fertilization (LN), low stocking rate (LS) paddock (229.1 g day^{-1}) was significantly ($P < 0.05$) lower than the ADG of weaner calves grazing the LN, high stocking rate (HS) and the high N (HN), LS respectively. The ADG of the animals in the HN, LS paddock was 482.7 g day^{-1} and in the LN, HS paddock was 310.6 g day^{-1}. The low ADG for the LS treatment was due to the low CP concentration of this paddock, with values as low as 55.1 g CP kg^{-1} DM recorded during the winter grazing period. Low pasture nutritive value during winter can potentially limit animal production.

During the spring grazing season the pasture contained an average of 101.0 g CP kg^{-1} DM, 639.1 g NDF kg^{-1} DM, 8.9 g Ca kg^{-1} DM and 2.1 g P kg^{-1} DM. The average leaf: stem ratio was 85:15, IVOMD was 717.5 g kg^{-1} OM and effective DM degradability (*in situ*) was 56.1 %. The average OM digestibility estimated with the alkane method varied between 720.8 to 768.3 g kg^{-1} depending on the alkane used and weather a correction was made for the faecal recovery of the alkane used. On average the forage available in the paddock with the LS had a significantly ($P < 0.05$) higher CP concentration, leaf: stem ratio and IVOMD, with a significantly ($P < 0.05$) lower NDF concentration than the HS paddock. This is probably due to the fact that in the HS paddock forage with a high nutritive value was removed at a higher rate. Irrespective of the calculation used, digestibility calculated by the alkane method did not differ significantly ($P > 0.05$) between paddocks at any time period. The average intake in the paddock with medium grazing stocking rate (MS) was significantly ($P < 0.05$) higher than the average for the other paddocks. The paddock with the MS

was managed to supply a pasture DM allowance of 2.5 % body weight (BW). The DM intake over the spring season was 2.2 % BW. The MS treatment supplied sufficient plant material without resulting in large accumulation of plant material. The ADG for the spring season was 110.5 g day^{-1} and averages for each paddock did not differ significantly ($P > 0.05$) from each other.

1 INTRODUCTION

Agricultural land is an extremely valuable resource. It is either directly or indirectly involved in the production of the majority of our food (including crops, meat and other animal products, such as milk and eggs).

Remarkable growth in global agricultural production was seen over the last 50 years. Although food production increased in Asia, Latin America and China, Africa did not show the same favourable trend. The projected future population growth as well as increased *per capita* consumption will result in an increased food demand. The key solution is a sustainable increase in local (Africa) food production in order to supply future population needs. The potential to meet the increased food demand is negatively affected by climate change, increasing water scarcity and pressures on the land available for food production. Land available for food production is decreasing because of growing cities, use of crops for bio-fuel production, increase in protected areas and soil erosion), causing food insecurity (The Royal Society, 2009).

The mining industry also contributes to the decrease in availability of land for agriculture. Open cast coal mining results in the removal of original vegetation, soil (Bradshaw, 1997) and agricultural systems. As described by Cairns (1983) management options for surface mined land include "(a) restoration to original condition, (b) rehabilitation of some desirable characteristics; (c) development of alternative *ecosystems* that may be quite unlike the original but may be desirable for a variety of reasons; (d) neglect of natural reclamation when evidence suggests that unaided natural processes will produce better results than human intervention." The author indicated that rehabilitation is an important option due to the fact that restoring land to its original condition is limited by a lack of knowledge about ecosystems and that scientists may not be able to determine the result of neglect.

Neglect is no longer an option due to South African legislative closure requirements (Act 28 of 2002). The sustainability of rehabilitation is affected by both the method used to rehabilitate and the post-mining land use. Overuse of heavy machinery and moving topsoil with moisture concentration higher than 10% will increase compaction and density of soil (Limpitlaw *et al.,* 2005). The excessive increase in soil compaction will inhibit root growth through the increase in resistance to root penetration, the reduction in water infiltration, aeration, and movement of water and nutrients as well as the buildup of toxic gasses and root exudates (Brady & Weil, 1996). This as well as misuse of the land (such as heavy overgrazing) will have a negative impact on rehabilitation (Limpitlaw *et al.,* 2005). The reduction of soil cover will lead to erosion and it is therefore essential for sustainability to determine the optimal grazing pressure for pastures established on rehabilitated mineland.

The use of mine waste water for irrigation created an opportunity to address the problems associated with the disposal of mine waste water and the shortage of irrigation water. Various studies using mine water from coal mines for irrigation have been conducted (Annandale *et al.,* 2001, 2006; Jovanovic *et al*., 1998, 2002; Mercuri *et al*., 2005). Yield for pasture and crop species tend to be higher (Jovanovic *et al.,* 1998) and tree survival were better (Mercuri *et al*., 2005) when irrigated with mine waste water compared to dry land production. Mine waste water from coal mines in Mpumalanga tends to be gypsiferous, being high in calcium (Ca) and sulphate ions (Annandale *et al.,* 2006). Soil appears to act as an effective salt sink, through the precipitation of salts (Annandale *et al*., 2001, 2006). Long term studies showed an increase in soil salinity with time (Jovanovic *et al*., 1998, 2002) although unacceptable levels of salinity in soil are not expected (Annandale *et al.*, 2001). The low potassium (K) concentration of these soils coupled with the high Ca concentration competing with K uptake could lead to K deficiencies in the plants (Jovanovic *et al*., 1998, 2002) making K fertilization essential. Excessive irrigation under these conditions will result in waterlogging and salinization of the root zone over time (Annandale *et al*., 2006) and should be prevented.

Tall fescue (*Festuca arundinacea*) is a grass tolerant to the saline conditions (Alshammary *et al*., 2004; Kobayashi *et al*., 2004) associated with mine rehabilitation and irrigation with mine waste water. In this study tall fescue, established on rehabilitated mine land and irrigated with mine waste water, was grazed by weaner calves.

2 LITERATURE REVIEW

Tall fescue (*Festuca arundinacea*) is a cool season, perennial grass native to Europe, North Africa, West and Central Asia, and Siberia (Gibson & Newman, 2001). It is adapted to a wide variety of soil, environmental and management conditions (Wilkinson & Mays, 1979).

2.1 GROWTH CHARACTERISTICS

The majority of dry matter (DM) production occurs during spring (about a third of its total production), after an initial reduction it is followed by an increase in growth in autumn (Lacefield *et. al.,* 2003). Depending on the cultivar of *F. arundinacea* used and defoliation frequency, expected annual DM yields of irrigated pasture in KwaZulu Natal ranged from 9.4 to 12.9 ton (t) ha^{-1} (Klug *et al.,* 2000). At the Hatfield Experimental Farm of the University of Pretoria the annual production of tall fescue ranged from 3.15 to 4.18 t ha^{-1} for unirrigated pastures fertilized with 100 kg N ha^{-1} and ranged from 11.22 - 11.59 for irrigated pastures fertilized with 400 kg N ha^{-1} (Grunow & Rabie, 1985). Callow *et al.* (2003) reported annual yields ranging from 10.8 to 11.9 t ha^{-1} for irrigated Dovey tall fescue in the subtropical environment of southern Queensland, Australia.

Optimum growth for most temperate (cool-season) grasses is at temperatures of between 20 and 25 °C, with growth nearly ceasing when temperatures rise above 30 to 35 °C (Cooper & Tainton, 1968). The optimal temperature for leaf growth of tall fescue is close to 25 °C (Robson, 1972).Though tall fescue can tolerate adverse soil conditions, it will not persist in deep sandy soils (Burns & Chamblee, 1979). Good moist soils, heavy to medium in texture with considerable humus are needed for optimum growth (Buckner & Cowan, 1973). The optimal soil pH for growth ranges from 6.5 to 8.0, although a wider range (pH 4.7 to 9.5) could be tolerated (Wilkinson & Mays, 1979). Kobayashi *et al*. (2004) studied the tolerance of tall fescue to three different salts: calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$) and sodium chloride (NaCl). These authors found that tall fescue growth was reduced by 50% at levels as high as 74.4, 61.0 and 141.0 mM for $CaCl_2$, $MgCl_2$ and NaCl respectively. Of the cool-season grasses in this study, tall fescue had the highest tolerance for all three salts. Alshammary *et al.* (2004) found a 50% shoot and root reduction of tall fescue at 14.2 and 21.5 dSm^{-1}, respectively. The maintenance of a relatively high root to shoot ratio appeared to be the adaptive mechanism for salinity tolerance in tall fescue (Alshammary *et al*., 2004)

Infection of tall fescue with the fungal endophyte *Acremonium coenophalum* results in increase tolerance to drought, high temperatures, insect and nematodes, (Pedersen *et al*., 1990; Marks & Clay, 1996) although cold tolerance is unaffected (Casler & Van Santen, 2008). Unfortunately this symbiotic relationship leads to reduced animal performance (Peters *et al.* 1992; Schmidt & Osborn, 1993; Thompson & Stuedemann, 1993) due to the ergopeptide alkaloids (possibly ergvaline) in these plants (Bacon, 1995). This reduction in animal production was not found when tall fescue inoculated with non-toxic endophytes, was grazed (Parish *et al.*, 2003a, 2003b; Nihsen *et al.,* 2004; Beck *et al.,* 2009; Johnson *et al*., 2012) and these pastures had a better stand persistence compared to endophyte free tall fescue (Nihson *et al*., 2004; Beck *et al.,* 2009). Except for ergovaline (Burns *et al.,* 2006) endophyte status did not seem to have a significant effect on the laboratory assessments of nutritive value.This includes *in vitro* dry matter digestibility (IVDMD), *in vitro* OM digestibility (IVOMD), neutral detergent fiber (NDF), acid detergent fiber (ADF), CP and total non-structural carbohydrates (Pedersen *et al*., 1990; Peters *et al*., 1992; Asay *et al.,* 2002; Burns *et al.,* 2006; Flores *et al.,* 2007). Tall fescue pastures in South Africa are generally considered endophyte free. Dugmore *et al.* (1992) stated that to the author's knowledge only one isolated incident of fescue toxicosis occurred in South Africa.

2.2 FEEDING VALUE (PASTURE QUALITY)

Ulyatt (1973) defined herbage feeding value as “a biological assessment of worth of a herbage in terms of animal production”, that is, “the animal production potential of the herbage under a given set of environmental circumstances”. Coleman & Moore (2003) indicated that “a sound theoretical definition for forage or feed quality is animal performance”. The production of weaner calves can be measured as their ADG. The grazing pressure to be applied is determined by the stocking rate that is decided on by the manager. The ADG of animals on pasture is highly correlated with the stocking rate applied and the amount of herbage present (Bransby *et al.,* 1988). Increasing stocking rates generally results in reduced ADG but an increase in beef production per unit land area (Vavra *et al.,* 1973; Derner *et al*., 2008). This is due to the effect of grazing management on quality (*sic*), yield, botanical composition and longevity of herbage (Bryant *et al*., 1970). Increasing stocking rates generally results in less available forage, lower quality (*sic*) and lower intake (Jung & Sahlu, 1989). The ADG for cattle range from 540 to 1190 g day^{-1} (Burns *et al*., 1991;Nihsen *et al.,* 2004; Beck *et al.*, 2009; Drewnoski *et al.,* 2009; Boland & Scaglia, 2011; Interrenate *et al.,* 2012; Johnson *et al*., 2012) and for lambs range from 90-319 g day^{-1} (Vecellio *et al.,* 1995; Parish *et al.*, 2003a) when grazing tall fescue cultivars without a toxic endophyte.

The upper limit of production any animal can achieve is determined by its genetic potential (Coleman & Moore, 2003). When all the nutrients required by the animal are available, feed is optimally utilized and only the genetic potential of the animal limits its production. The first limiting nutrient determines the extent to which the animal will reach its genetic potential. This assumption that animal performance is related closely to intake of available nutrients is the basis of most feeding standards and models (Coleman & Moore, 2003).

Feeding value is a function of intake and nutritive value of the herbage, while the nutritive value is a function of the digested nutrients and the efficiency of nutrient utilization for maintenance and production (Ulyatt, 1973). Thus, the term nutritive value "includes nutrient composition (i.e., protein, carbohydrates, vitamins, and minerals) of the feed, availability (digestibility) of nutrients and energy, and efficiency of nutrient and energy utilization" (Coleman & Moore, 2003). Burns *et al.* (1991) found a strong correlation (r = 0.92) between IVDMD of cool season grasses and the ADG of steers. Coleman & Moore (2003) stated that in fibrous feed, protein and energy are usually the first nutrients to limit animal production, while vitamins and minerals may limit animal production at chronic levels.

Table 2.1 Chemical composition (g kg^{-1} DM) reported for tall fescue pasture in literature

CP	NDF	ADF	Hemicellulose	Cellulose	Lignin	Reference
67-197						Collins & Balasko 1981
136-177	556-715	333-393			39-60	Bond *et al*. (1984)
125-221						Bosworth *et al.* (1985)
214-236						Grunow & Rabie (1985)
97-169	591-712					Collins (1991)
150-201	607-670	329-393				Howard *et al.* (1992)
116- 217						Dugmore *et al.* (1992)
145-166	488-536	285-294			24-30	Cherney *et al*. (1993)
119-169	609-672	322-363				Beconi *et al.* (1995)
134-175	591-653	305-355				Kabiligi *et al.* (1995)
88-213	463-681					Burns & Chamblee (2000)
163-176	459-474					Asay *et al.* (2002)
88-116	523-701	298-462				Hedtchke *et al.* (2002)
103-149						Parish *et al.* (2003a)
160-204	477-602	266-314				Parish *et al.* (2003b)
104 - 125	522 - 620	373 - 317		202 - 290	22 - 48	Burns *et al.* (2006)
119-199	474 - 653	230 - 432	288 - 340	250 - 281	37- 100	Poore *et al.* (2006)
112-186		300-313				Drapeau *et al*. (2007)
127 - 156	565 - 678	277 - 349	303 - 349	243- 277	26 - 37	Flores *et al.* (2007)
87-270	501-631	209-348				Donaghy *et al*. (2008)
97-141	557-657					Volesky *et al.* (2008)
82-178	526-712	269-417				Stewart *et al.* (2008)
125 - 283	308 - 635	180 - 423				Beck *et al.* (2009)
109 - 122	604 - 629	324-340				Boland & Scaglia (2011)
99-254	367-583					Raeside *et al.* (2012)
118-232	435-602	237-365				Interrenate *et al*. (2012)
67-283	**308-715**	**180-432**	**288-349**	**202-290**	**22-100**	**Range**

Some of the components of nutritive value reported for tall fescue pasture in literature are shown in Table 2.1 and Table 2.2. The metabolisable energy (ME) and IVDMD was not included in the Table. In tall fescue the ME ranged between 9.2 – 11.3 MJ kg^{-1} DM (Donaghy *et al*., 2008) and

IVDMD ranged between 324 – 839 g kg^{-1} (Balasko, 1977; Collins & Balasko, 1981; Eck *et al.,* 1981; Bond *et al.,* 1984; Brosworth *et al.,* 1985; Burns *et al.,* 1991, Collins, 1991; Fisher *et al.,* 1991; Cherney *et al.,* 1993; Burns & Chamblee, 2000; Parish *et al.*, 2003a; Volesky *et al*.; 2008; Raesidae *et al.,* 2012).

Table 2.2 Concentration of major minerals (g kg^{-1} DM) reported for tall fescue pasture in literature

Ca	P	Mg	S	K	Reference
2.2 - 3.6	1.7 - 2.3	0.8 - 2.0		7.9 - 17.7	Balasko (1977)
3.6 - 4.6	2.2-3.3	2.1 - 2.6	2.5 - 3.0	22.7 - 32.0	Powell *et al.* (1978)
3.2 - 6.5	1.1 - 2.7	1.0 - 2.8		4.1 - 13.9	Collins & Balasko (1981)
4.3	1.7	2.4		26.6	Eck *et al.* (1981)
4.5 - 5.5	1.2 - 3.2	2.2 - 2.6	1.2 - 1.3	16.9 - 34.9	Murray *et al.* (1984)
2.7 - 3.1	1.4 - 1.9	1.2 - 1.3		14 - 17	Bosworth *et al.* (1985)
4.6 - 5.0	2.8 - 2.9	4.2 - 4.4			Grunow & Rabie (1985)
1.9 - 4.6	1.8 - 2.9	0.8 - 3.4		19.1 - 30.4	Dugmore *et al.* (1992)
3.4 - 5.2	2.0 - 3.1	2.0 - 2.9	1.8 - 2.5	21.2 - 31.4	Poore *et al.* (2006)
1.9 - 6.5	**1.1 - 3.3**	**0.8 - 4.4**	**1.2 - 3.0**	**4.1 - 34.9**	**Range**

2.3 FACTORS INFLUENCING PASTURE NUTRITIVE VALUE

2.3.1 Cultivar

The choice of cultivar influences the nutritive value of the pasture. This is illustrated in the following three studies.

A two year field experiment was conducted by Collins & Casler (1990) to evaluate the effects of cultivar on forage quality of five cool-season grasses during spring and early summer. The three tall fescue cultivars ('KY 31', 'MO 96' and 'Kenhy') studied, differed significantly in N concentration, with later maturing cultivars within species generally having the highest values. No significant differences in NDF, ADF and IVDMD were found between these tall fescue cultivars.

Similarly Drapeau *et al.* (2007) found significant ($P < 0.05$) differences in concentrations of CP, and water soluble carbohydrates (WSC) between the cultivars Courtenay, Kokanee and Montebello. The ADF concentration were significantly ($P < 0.05$) higher in the Montebello cultivar compared to the Courtenay and Kokanee cultivars (Drapeau *et al*., 2007). A study by Asay *et al.* (2002) comparing 10 tall fescue cultivars showed significant differences for CP, NDF and *in vitro* true digestibility between cultivars.

2.3.2 Stage of growth (maturity) and plant parts

Generally the increase of maturity of the pasture is associated with a decrease in CP, moisture, total ash, digestibility and metabolizabe energy (ME) while the fiber concentration increases (McDonald *et al.,* 2001). The effect of maturity on digestibility is complicated by the fact that digestibility tends to remain constant during spring (McDonald *et al.,* 2001).

Various studies have shown a decline in digestibility associated with an increase in fiber concentration with the increase in maturity of tall fescue (Pendlum *et al.,* 1980; Dugmore *et al.,* 1992; Howard *et al.,* 1992; Cherney *et al.,* 1993; Elizalde *et al.* 1999a, 1999b; Callow *et al*. 2003; Burns *et al*., 2006; Donaghy *et al*., 2008). This trend is generally a result of a decline in leaf: stem ratio and an increase in indigestible fiber (Nordheim-Viken *et al.,* 2009). Advancing maturity of tall fescue is associated with a reduction in the CP concentration (Pendlum *et al.,* 1980; Murray, 1984; Bosworth *et al*., 1985; Dugmore *et al.,* 1992; Howard *et al.,* 1992; Cherney *et al.* 1995; Callow *et al*. 2003; Donaghy *et al*., 2008) as well as ME (Donaghy *et al*., 2008) and most minerals including Ca and P (Powell *et al*., 1978; Pendlum *et al.,* 1980; Murray, 1984; Bosworth *et al*., 1985). Although Sinclair *et al.* (2006) found an increase in Ca concentration of the leaf of irrigated tall fescue over the regrowth period of 60 days (1 Aug to 6 Oct 2000; Australia), leaf P concentration did not show any significant variation. Elizalde *et al.* (1999a) reported with increasing maturity in tall fescue a NDF increased of 0.44% day^{-1}, a ADF increase of 0.41%% day^{-1} and a CP decrease of 0.30% day^{-1}. Cherney *et al.* (1993) found that IVDMD of cool season grasses decreased with maturity at a rate ranging from 0.57 to 0.78 day^{-1} and it had a high negative correlation with lignin (Cherney *et al*., 1993).

In the study by Burns *et al.* (2006) the chemical composition of tall fescue leaf material ranged from 138-208 g CP kg^{-1} DM, 414-458 g NDF kg^{-1} DM and 205-243 g ADF kg^{-1} DM. Stem material generally had a poorer chemical composition compared to leaf at each time period and ranged from 91-110 g CP kg^{-1} DM, 410-519 g NDF kg^{-1} DM and 195-264 g ADF kg^{-1} DM. In the study by Chaves *et al.* (2006) tall fescue leaf material contained 305 g DM kg^{-1} material, 150 g CP kg^{-1} DM, 560 g NDF kg^{-1} DM, 339 g ADF kg^{-1} DM, 45 g NSC kg^{-1} DM and 9.0 MJ ME kg^{-1} DM. In agreement with Burns *et al.* (2006) stem material of tall fescue was poorer in chemical composition and contained 361 g DM kg^{-1} material, 60 g CP kg^{-1} DM, 657 g NDF kg^{-1} DM, 390g ADF kg^{-1} DM, 71 g NSC kg^{-1} DM and 7.9 MJ ME kg^{-1} DM. MacAdam *et al.* (1997) found significantly higher concentrations of Ca in tall fescue leaf compared to stem material. The above mentioned studies demonstrate the difference in nutritive value between leaf and stem of tall fescue.

2.3.3 Stocking rate (grazing intensity)

Donaghy *et al.* (2008) investigated the effect of defoliation management on tall fescue quality. The two-leaf and four-leaf stage of regrowth was identified as the minimum and maximum defoliation interval respectively. Frequent defoliation maximized quality, but minimized yields, with the opposite being true for infrequent defoliation.

The high stocking rate in the study of Jung & Sahlu (1989) was too low to suppress physiological maturation and was associated with lower forage quality at later periods compared to a low stocking rate. The lower forage quality (lower CP and IVDMD, higher NDF) was attributed to a higher rate of removal of high-quality forage during periods of slow forage regrowth.

Vavra *et al.* (1973) found no significant difference in CP concentration, DM digestibility and dietary energy value of blue grama dominated pasture due to grazing intensity. These authors indicated that this might be due to sufficient regrowth in the heavily stocking rate pasture to keep forage quality at a similar level as the low stocking rate pasture.

2.3.4 Nitrogen fertilization

Hedtcke *et al.* (2002) found that N fertilization of tall fescue and other cool season grasses increased CP, while NDF, ADF and IVOMD were unaffected. Collins (1991) also found an increase in CP concentration of tall fescue when N fertilization was increased. Higher levels of N fertilization generally results in higher concentrations of total non structural carbohydrates (Balasko, 1977; Collins & Balasko, 1981) and CP in tall fescue (Balasko, 1977; Collins & Balasko, 1981; Eck *et al.,* 1981; Peyraud & Astigarraga, 1998; Hedtcke *et al.,* 2002; Wolf & Opitz von Boverfeld, 2003; Burns, 2009). The effect of N fertilization on digestibility and NDF are highly variable. Tall fescue digestibility and NDF concentration can either be unaffected (Collins, 1991; Peyraud & Astigarraga, 1998; Hedtcke *et al.,* 2002) or N fertilization can increase DMD (Balasko, 1977; Collins, 1991; Burns, 2009) and decrease NDF concentration (Burns, 2009). Collins & Balasko (1981) found a decrease in IVDMD with increased rates of N fertilization. To limit the risk of poisoning associated with high levels of NH_3-N (ammonia-nitrogen), Eck *et al.,* 1981 suggested a maximum level of 504 kg N ha^{-1} $year^{-1}$ when irrigated for maximal growth, or 336 kg N ha^{-1} $year^{-1}$ when irrigation is insufficient.

2.3.5 Soil conditions

Soil compaction usually reduce plant uptake of nutrients including N, P and Ca (Lipiec &

Stępniewski, 1995). Lower accessibility of plants to N and greater denitrification in compacted soils resulted in greater losses of N compared to non-compacted soils (Lipiec & Stępniewski, 1995). The excessive increase in soil compaction will inhibit root growth through the increase in resistance to root penetration, the reduction in water infiltration, aeration, and movement of water and nutrients as well as the buildup of toxic gasses and root exudates (Brady & Weil, 1996).

Pasture nutritive value can be affected by soil moisture conditions. Quality trends of 10 tall fescue cultivars over different levels of irrigation were studied by Asay *et al.* (2002). These authors found a near linear increase in CP concentration with decreasing levels of irrigation applied; however, total protein yield decreased with a trend closely following that of forage yield. With each millimetre increase in water received per day, CP decreased 20 g kg^{-1} across cultivars, harvests and years. No consistent trends were detected for NDF and *in vitro* true digestibility across water levels. At the late-season harvest and the lower irrigation levels NDF values tended to be lower and *in vitro* true digestibility higher (Asay *et al.,* 2002). Similar results were seen in the a study conducted by Eck *et al.* (1981) where the total N was higher and Ca lower in tall fescue receiving the lower level of irrigation, while the IVDMD and P level was unaffected.

2.3.6 Temperature

Plants grow and mature less rapidly in temperate areas with a reasonably uniform distribution of rainfall compared to those in warmer climates. Protein and P concentrations decline and fiber concentration rises at a slower rate in temperate climates. These plants can thus be utilized at an earlier stage of growth when nutritive value is high. Herbage available in the tropics (commonly fibrous and high in moisture concentration in the wet areas with desiccated herbage as standing hay in drier areas) typically have a digestibility value of 0.1-0.15 units lower than temperate herbage (McDonald *et al.,* 2001).

2.3.7 Frost

Sakai & Larcher (1987) defined frost as “a condition in which temperatures fall below 0°C”. Freezing of water inside the plant occurs at temperatures lower than 0 °C. The level to which the temperature drops during frost, the duration and time of onset, whether it is confined to the area surrounding the shoot or if it also penetrates the ground, is of great significance to the plant. In freezing tolerant cells, death occurs at temperatures corresponding to a specific threshold for dehydration tolerance. The most frequent and clearest indication of freezing injury is the discoloration of any plant part. Tall fescue is potentially resistant to frost (Sakai & Larcher, 1987).

Naturally frozen tissues rarely show ice formation within living cells. These ice crystals form in extracellular spaces, water then diffuses out of the cells and as a result the cells shrink. When ice crystals melt in frost hardy plants the water diffuses back into the cells and they resume their metabolism. Damage to membranes and other cellular components during thawing may occur in non-acclimated plants. As a result water cannot re-enter the cells completely and metabolism cannot be resumed (Salisbury & Ross, 1992).

When leaf or stem death occurs, as a result of senescence or frost, soluble material is translocated or metabolised and primarily structural material remains resulting in lower digestibility (Beaty & Engel, 1980).

2.3.8 Other environmental factors

Tall fescue quality shows daily diurnal variation with a higher concentration of soluble carbohydrates in the late afternoon compared to early morning (Burns, 2009). Generally increasing photoperiod (spring and summer) has a positive effect on quality which is often dampened by the negative effect of accompanying increasing temperatures (Buxton, 1996). Burns *et al*. (2002) examined the nutritive value of tall fescue at the Reedy Creek Road Field Laboratory, NC. Data were collected from May to Nov across three years. Generally IVDMD, CP and WSC were the lowest and NDF, ADF, hemicellulose, cellulose and lignin were the highest during July (middle summer). In the study by Bagley *et al*. (1983) the digestibility of DM, OM, CP and ADF for tall fescue was higher in summer compared to winter.

2.4 INTAKE CONTROL

Forage intake in ruminants is thought to be controlled through the complex integration of signals from various receptors to the central nervous system (CNS). Information is transmitted to the CNS via several routes from receptors in various parts of the digestive tract and associated organs, which are sensitive to several physical and chemical stimuli. It is integrated with information from special senses and memory into the food intake-controlling system. The evidence supporting this theory of additivity has been reviewed elsewhere (Allen, 1996; Forbes, 1996).

Physical distension in the gastrointestinal tract limits intake of diets with low digestibility (Allen, 1996). Conrad *et al.* (1964) suggested intake is limited by the gut fill up to a point in digestibility beyond which the relationship between intake and digestibility becomes negative and controlled by energy requirements. Allen (1996) stated that this is “likely a convenient mathematical simplification” and that as digestibility increase the effect of fill on intake gradually diminishes.

Intake and retention time seems to be negatively correlated (Allen, 1996). For maximum decrease in intake both ruminal capacity and ruminal DM disappearance must be limiting. The energy requirements of an animal, its ability to alter flow from the reticulorumen and the capacity of the reticulorumen, as well as the energy density and filling effect of the diet affect the response to inert fill inserted into the retiulorumen. Particle size and density also influences the flow from the reticulorumen. Large particles with a lower density show higher resistance to flow than small, high density particles. At first, particle density is determined by gasses trapped within particles, from swallowed air or produced by particle associated microbes. As fermentable organic matter (OM) diminishes, gas production is reduced and density increases. Intake is highly correlated with the NDF concentration of forages, but its filling effect varies with differences in initial particle size, particle fragility, as well as rate and extent of NDF digestion (Allen, 1996).

Microbial fermentation weakens particles to facilitate particle size reduction during rumination. Lignin is the major plant cell component that limits digestion, probably through shielding of polysaccharides from enzyme hydrolysis. Lignin concentration may be negatively correlated with the extent of NDF digestion and possibly also the rate of NDF digestion (Jung & Allen, 1995).

The effect of nutrients on feed intake control was reviewed by Faverdin (1999). Volatile fatty acids (VFA), the main energy source for ruminants, generally accounts for 50-75% of digested energy. Short term infusion of VFA decrease feed intake, however effects tend to disappear with long term infusion, except for proprionate. The effects of VFA on intake appear to be primarily due to osmolarity problems, with only proprionate showing an unrelated specific effecton intake at the mesenteric or portal veins. Nitrogenous nutrients do not seem to affect short term feed intake, unless there is a great excess of N in the rumen (Faverdin, 1999).

2.5 FACTORS AFFECTING INTAKE

Intakes by grazing ruminants are affected by animal and management controlled factors. The major animal-related factors affecting level of voluntary intake appear to be body size and physiological stage of ruminants. While the major management-controlled variables affecting intake of these animals are the type and amount of supplementation, forage availability and grazing intensity (Allison, 1985).

Pasture intake is a function of the time spent grazing and intake rate. Intake rate in turn is a function of bite mass and bite rate. Both animal and sward characteristics influence bite mass and bite rate (Allden & Whittaker, 1970).

2.5.1 Animal factors

Romney & Gill (2000) stated that across animal species, size of animals is the factor most closely correlated with intake, with larger animals having higher intakes. The fasting metabolism (and thus energy requirements) of larger animals is higher than that of smaller animals, but per unit of live weight, it is higher for small animals (McDonald *et al*., 2001). Fasting metabolism (and therefore intake) is more proportional to the metabolic live weight ($LW^{0.75}$) of animals than to their weight (McDonald *et al*., 2001). Higher intakes per unit body weight have been observed for younger compared to older animals (Hunter & Siebert, 1986; Romney & Gill, 2000) and lactating or pregnant versus dry animals (Hunter & Siebert, 1986; Vanzant *et al.,* 1991). Reduced intakes are usually associated with infectious, metabolic and parasitic diseases (Weston, 1982).

2.5.2 Cultivar

In the study by Burns & Fisher (2010) intake of tall fescue hay for three different cultivars (HM4, MaxQ and Cajun) were determined. Goats consumed significantly ($P < 0.05$) less when fed Cajun (1.62 kg DM 100^{-1} kg BW) compared to HM4 (2.44 kg DM 100^{-1} kg BW) and MaxQ. (2.57 kg DM 100^{-1} kg BW). The apparent digestibility of DM and fiber fractions (NDF, ADF, hemicellulose, cellulose and lignin) did not differ significantly ($P > 0.05$) between these three tall fescue cultivars during the goat trial. Significantly ($P < 0.05$) higher intakes were found for steers fed MaxQ (1.98 kg DM 100^{-1} kg BW) compared to HM4 (2.14 kg DM 100^{-1} kg BW, Cajun was not fed). During the steer trial the apparent digestibility of DM and fiber fractions of MaxQ hay was significantly ($P < 0.01$) higher compared to HM4. This difference in digestibility seen in the steer trail could explain the contrast in intake results compared to the goat trial.

2.5.3 Stage of growth (maturity) and plant parts

Intake generally decreases with increasing maturity of cool season grasses (Pendlum *et al.,* 1980; Reid *et al.,* 1978; Howard *et al.,* 1992) and could be as a result of higher proportions in stem, lower intakes of leaf and stem, and nutritional deficiencies such as Ca, P and Mg (Minson, 1990).
Leaf intake is generally higher compared to stem in grasses which seems to be due to its shorter retention time in the rumen and not due to differences in digestibility as such. This shorter retention time might be due to a higher rate of digestion of NDF, higher passage of NDF from the rumen and higher potential digestibility of the leaf (Allison, 1985).

2.5.4 Nitrogen fertilization

Nitrogen fertilization does not seem to have a consistent effect on intake (Minson, 1990). If forage of the same age were compared DM intake is usually unaffected by N fertilization (Peyraud & Astigarraga, 1998).

2.5.5 Water concentration

Kenney *et al.* (1984) showed that with increasing water concentration of fresh herbage, total intake increased and DM intake was reduced up to a DM concentration of 40% (60% water) after which it remained relatively constant. External water (or surface water) was shown to result in a reduction in DM intake (Butris & Phillips, 1987; Phillips *et al*., 1991) with no effect on the total intake (Butris & Phillips, 1987). Recent studies (Cabrera Estrada *et al*., 2003, 2004) found that external water did not affect DM intake. Cabrera Estrada *et al*. (2004) concluded that only internal and not external plant water limited DM intake.

2.5.6 Environmental factors

Mammals (including cattle and sheep) need to maintain a thermal balance. The rate of heat loss is influenced by the animal's environment (temperature, relative humidity, air velocity and solar radiation) as well as its insulation. The thermal neutral zone refers to the temperature between the points where the animal needs to increase or reduce its heat production in order to maintain a thermal balance (McDonald *et al.,* 2001).

Temperatures above the thermal neutral zone are usually associated with lower intakes and temperatures below this zone normally result in higher intakes (Weston, 1982; McDonald *et al.,* 2001), provided severe cold stress did not occur (Weston, 1982). Lower intakes are also associated with high solar radiation as well as relative humidity (Weston, 1982).

Rhind *et al.* (2002) reviewed the current understanding regarding seasonality of appetite and voluntary intake. During long-day photoperiods animals exhibit higher intakes than during short-day photoperiods.

2.5.7 Sward structure

Allden & Whittaker (1970), found a sevenfold increase in herbage intake rate by sheep grazing pastures of 7.7 cm compared to 3.7 cm tiller length. At greater tiller lengths intake rate remained constant. This was associated with an almost linear increase in bite size, while the rate of biting decreased after an initial small increase. In a study by Chacon & Stobbs (1976) it was found that later stages of progressive defoliation were associated with reduced grazing time, bite mass and bite size in cattle. These authors concluded that intake was restricted by the low leaf density. Barre *et al.* (2006) found significantly lower intakes at shorter leaf blade length, but failed to find significant differences in fresh matter intake with significant differences in tiller density.

2.5.8 Supplementation

When abundant forage is available overall DM intake tends to increase with supplementation, although intake of the basal herbage may be either increased or decreased (Minson, 1990; Romney & Gill, 2000). When the supplement supplies a limiting nutrient (e.g. protein or phosphorous), intake of feed with a poor nutritive value may be increased by giving a supplement (Moore *et al*., 1999; Romney & Gill, 2000; Coleman & Moore, 2003).

Feeding an energy supplement tends to replace intake of the fibrous feed (substitution). When forage allowance limits intake, the effect of energy supplementation will have little adverse effects on forage intake. The mean substitution coefficient of 0.69 for grazed forage varies with type of supplement, time of feeding and quality of forage (Minson, 1990). The degree of substitution is greater when supplements are high in readily fermentable carbohydrate, due to depression of digestibility of the roughage fraction (Romney & Gill, 2000).

2.5.9 Stocking rate (grazing intensity)

During a three year study smooth bromegrass *(Bromus inermis)* pasture was divided into four paddocks and stocked with either 15 or 30 lambs per ha. The high stocking rate resulted in significantly ($P < 0.01$) less total available forage and animals tended ($P < 0.10$) to consume less DM (Jung & Shalu, 1989). Dalley *et al.* (1999) studied the effect of herbage allowance on intake of perennial ryegrass (*Lolium perenne*) dominant pastures in spring. With increasing herbage allowance (i.e. lower stocking rates) intake increased due to an increase in the rate of intake, with no significant change in grazing time. Low pasture availability reduce the opportunity for selective gazing and decreasing the quality (*sic*) of ingested material (Bryant *et al*., 1970). Sollenberger & Vanzant (2011) reviewed the interrelationship between nutritive value, available forage and animal performance. These authors indicated that the effect of higher stocking rate on ADG is primarily the result of reduced intakes due to lower pasture availability.

2.6 INTAKE AND DIGESTIBILITY ESTIMATION

2.6.1 Alkane technique

Primarily odd-chain alkanes are present in the wax layer of all higher plants. Alkane concentration in herbage differs between plant species and plant parts (Dove & Mayes, 1991; Zhang *et al*., 2004) and can be influenced by sampling date (Zhang *et al*., 2004; Cortes *et al*. 2005).

Several reviews have been published on the use of alkanes as markers to determine intake and digestibility (Dove & Mayes 1991, 2005, 2006). Although faecal recovery is incomplete, voluntary intake of grazing animals can be estimated by the concurrent use of dosed and herbage alkanes of adjacent chain length. Intake is estimated directly from alkane concentrations with the herbage alkane functioning as internal digestibility marker and the dosed alkane functions as external, faecal output marker (Dove & Mayes 1991, 2005, 2006).

Dove & Mayes (2006) summarised the methods for the administration of even-chain alkanes. This includes paper pellet, gelatine capsule, paper bung, paper filter, alkane-labelled feed, alkane suspension, alkane emulsion and intra-ruminal alkane controlled-release device (CRD). Errors associated with daily dosing of alkanes, due to diurnal variation, and the need for daily dosing can be avoided with the use of a CRD. The CRD is dosed to an animal and releases C_{32} and C_{36} at predictable rates for 20 days after insertion (Dove & Mayes, 2006). The manufacturer recommends a sampling period between days 8 and 16 when a constant release rate and steady state exists (Argenta Manufacturing Ltd, 2 Sterling Ave, Manurewa, Auckland, New Zealand).

The use of alkanes administered by CRD to estimate intake can be relatively accurate under three conditions. These are firstly that the alkane pair used has similar faecal recovery rates (Berry *et al.,* 2000, Dove & Mayes 1991, 2006; Oliván *et al.* 2007), secondly, that the release rate of the CRD used was determined for the trial situation (Ferreira *et al*., 2004; De Oliveira *et al*., 2008) and thirdly that the pasture sample was representative of material ingested by the animals (Dove & Mayes, 1991). Although hand plucked samples might be adequate in monospecific pastures, in more complex pastures oesophageally fistulated animals are required to collect representative samples (Dove & Mayes, 1991). Accuracy of intake estimates does not seem to be influenced by level of feeding, feeding frequency or number of CRDs administered (Dove *et al.,* 2002). When a CRD was used in cattle, faecal grab sampling, time did not influence accuracy of intake estimation (Berry *et al.,* 2000; Ferreira *et al.,* 2004), provided that the alkane pair used had similar faecal recovery rates.

Accurate intake estimates have been obtained using C_{32} with either C_{31} or C_{33} (Dove *et al.,* 2002; Ferreira *et al*., 2004) when faecal recovery rates were similar. Oliván *et al.* (2007) found considerably higher faecal recoveries of C_{32} (0.95, average) compared to C_{31} (0.75 on average) and C_{33} (0.78 on average) resulting in a significant underestimation of intake. In the study by Berry *et al.* (2000) similar recoveries of C_{33} and C_{32} (0.85 and 0.87) resulted in accurate intake estimates while lower recovery of C_{31} (0.76) than C_{32} resulted in underestimation of intake. Sandberg *et al.* (2000) determined that in yearling steers the faecal recovery of C_{31} also varied between forages.

Digestibility can be estimated using the C_{36} to determine faecal output together with intake estimation using alkanes of adjacent chain length or alternatively by using natural alkanes as the internal marker. The alkane method can accurately estimate the *in vivo* digestibility although higher variation can prevent detection of small differences in digestibility (Dove *et al.,* 2002). The major advantage of the alkane method is that digestibility and intake can be predicted at the same time for individual animals (Dove & Mayes, 1991, 2005, 2006; Decruyenaere *et al.,* 2009).

2.7 HYPOTHESIS

The aims of this study were to quantify,

a) animal performance and pasture nutritive value at different levels of N fertilization during pasture establishment, and
b) intake, animal performance (defined as ADG) and pasture nutritive value when different stocking rates are applied

With the first hypotheses:

H_0: The level of N fertilization during pasture establishment will not affect animal performance and nutritive value of *Festuca arundinacea*.
H_1: The level of N fertilization during pasture establishment will affect animal performance and nutritive value of *Festuca arundinacea*.

H_0: Stocking rate will not affect intake, animal performance and nutritive value of *Festuca arundinacea*.
H_1: Stocking rate will affect intake, animal performance and nutritive value of *Festuca arundinacea*.

3 MATERIALS AND METHODS

The protocol for this study was submitted and received ethical approval from the animal use and care committee of the University of Pretoria (ec036-09).

3.1 EXPERIMENTAL SITE

The study was conducted on a centre pivot in the eMalahleni area of the Mpumalanga Province, South Africa. This high lying site is sub-tropical with a summer rainfall. The average precipitation is about 700 mm per annum.

The experimental site, previously used for open cast coal mining, was rehabilitated prior to the study. Coal mine spoil material was covered with a sandy clay soil of 40 cm in depth. The soil properties at this site were determined by Mosebi (2010). The bulk density of the cover soil varied form 1.80 g cm^{-3} at 0-20 cm to 1.90 g cm^{-3} at 20-40 cm depths. The nutrient concentrations in the soil were as follows: Ca (2462 mg kg^{-1}), P (17 mg kg^{-1}), K (159 mg kg^{-1}), Mg (448 mg kg^{-1}) and Na (94 mg kg^{-1}).

In June 2007 tall fescue (*Festuca arundinacea* cv. Dovey) was established on rehabilitated mine land at a seeding rate of 35 kg ha^{-1}. The pasture was divided into seven paddocks, paddock A-F and a centre paddock (Figure 3.1).

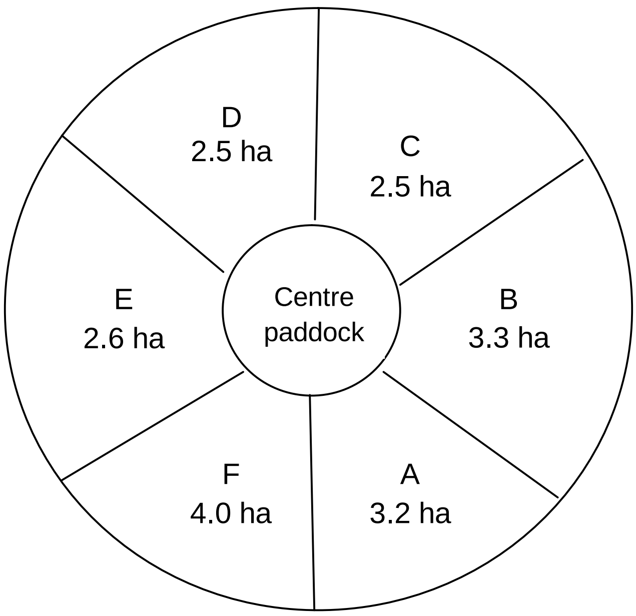

Figure 3.1 Paddock description of the tall fescue pasture

The pasture was fertilized in June 2007 with 110 kg P ha^{-1} and 150 kg N ha^{-1} (paddock A received double the amount of N, see Figure 3.1). In November 2007 the whole experimental site was cut down to an average of 5 cm and the plant material was not removed. A second application of N occurred during March 2008, at a rate of 150 kg ha^{-1} in all the paddocks. The pasture has been irrigated with mine waste water with a pH of 7.6 and an electrical conductivity of 435.25 mS m^{-1}. Mine waste water from coal mines in Mpumalanga tends to be gypsiferous, being high in calcium (Ca) and sulphate ions (Annandale *et al.,* 2006). The chemical analysis of the mine waste water used in this study is summarised in Table 3.1.

Table 3.1 Analysis of mine waste water used for irrigation

Mineral	concentration (mg L^{-1})
S	1176.8
Ca	563.0
Mg	498.8
Na	96.8
NO_3^-	53.3
Cl	38.9
K	37.1
NH_4^+	18.3
P	0.1
B	0.1
Fe	0.0
Cu	0.0
Mn	0.0
Zn	0.0
CO_3^{2-}	0.0
HCO_3^-	0.0

3.2 DURATION OF THE PROJECT

On the 27th of May 2008 a group of 197 cross bred weaner calves and four cannulated steers were moved to the centre paddock. Following an adaptation period of a week, all the animals were weighed on the 3rdof June 2008. Animals were ranked according to weights and randomly assigned to treatments on the 6th of June 2008 (see Section 3.3.2, extra animals were moved to a different cite).

Data were collected during two respective periods: 6 June to 16 July 2008 (season 1) and 27 August to 5 November 2008 (season 2). During the period from 16 July to 26 August 2008 animals were allowed to freely graze the centre paddock as well as paddock A, B and C.

3.3 SEASON ONE

Climatic factors were quantified using an automatic weather station and are presented in Table 3.2. The minimum and maximum temperatures were -4.5°C and 23.2°C respectively. No rain occurred during season 1 and a mean weekly irrigation level of 10 mm was measured using manual rain gauges. The first frost for the season occurred during the morning of the 26th of June 2008.

Table 3.2 Climatic data during season 1

	Temperature (°C)		**Wind speed (m/s)**		**Relative humidity (%)**		**Solar radiation (W/m2)**
	max	min	max	min	max	min	average
3- 13 Jun	22.2	-2.0	8.3	0.7	100	10.6	44.3
13-20 Jun	23.2	-0.4	9.2	0.6	100	18.3	44.6
20 - 27 Jun	20.7	-2.1	8.6	0.8	100	11.8	40.7
27 Jun - 4 Jul	21.8	-2.5	9.2	0.9	100	14.0	34.5
4 - 11 Jul	22.4	-4.5	12.3	1.2	100	13.0	38.3
11 - 18 Jul	21.9	-3.1	6.8	0.8	100	22.6	47.0

Paddock A, B and C (3.2, 3.3 and 2.5 ha in size) were grazed from 6 June to 16 July 2008 (a period of six weeks), while paddock D, E and F (2.5, 2.6 and 4 ha in size) were rested.

3.3.1 Treatments

Treatment 1: Paddock A was fertilized with 300 kg N ha^{-1} in June 2007 and on 6 June 2008 it was stocked to achieve a DM pasture allowance of 3% of the total live weight (LW) of animals.
Treatment 2: Paddock B was fertilized with 150 kg N ha^{-1} in June 2007 and on 6 June 2008 it was stocked to achieve a DM pasture allowance of 3% of the total LW of animals.
Treatment 3: Paddock C was fertilized with 150 kg N ha^{-1} in June 2007 and on 6 June 2008 it was stocked to achieve a DM pasture allowance of 2%of the total LW of animals.

3.3.2 Experimental Design

Fixed stocking rates were applied (Wheeler *et al.,* 1973) for each paddock during the observation period, to achieve the grazing pressure as was decided on. The terms stocking rate and grazing pressure refers to the number of animals per unit of area and the number of animals per unit of available forage respectively (Wheeler *et al.,* 1973). To achieve the decided on grazing pressure a certain stocking rate needed to be applied. Following a week of adaptation in the centre paddock, four cannulated steers, with an average weight of 610 kg, and 141 cross bred weaner calves with an average weight of 146 kg were randomly divided between paddocks A-C to achieve the grazing pressure decided on. The steers were cannulated for the use in a previous study as described by Vermaak (2011).

Paddock A where treatment 1 was applied had a pasture availability of 4036.8 kg DM ha^{-1} at the start of season 1 and was stocked with two of the rumen cannulated steers and 46 randomly selected crossbred weaner calves. Treatment 2 was applied in paddock B where a pasture availability of 3596.4 kg DM ha^{-1} was measured and it was stocked with one rumen cannulated steer and 45 randomly selected cross bred weaner calves. Paddock C had a pasture availability of 3490.0 DM ha^{-1} at the start of season 1 and was stocked with one rumen cannulated steer and 50 crossbred weaner calves to achieve the grazing pressure difference between treatment 3 in comparison to treatment 2. Stocking rate was calculated for a period of 60 days, although the trial was terminated two weeks early due to an extremely low pasture availability and persistent animal weight losses.

Three of the four cannulated steers, to be used for the determination of pasture quality, rotated between paddocks on a weekly basis (treatments) following a 3 x 3 Latin square design (Table 3.4). The fourth cannulated steer was placed in the paddock with the lightest stocking rate (paddock A). Rotation of the cannulated steers was needed to take animal effects into account and provision was made for an adaptation period of four days of each week.

Table 3.3 Experimental design season 2 (Latin square)

	Animal		
Week	a	b	c
1, 4 and 7	Paddock D	Paddock E	Paddock F
2, 5 and 8	Paddock F	Paddock D	Paddock E
3, 6 and 9	Paddock E	Paddock F	Paddock D

Clipped samples of the pasture were taken on a weekly basis from 24 quadrants in each paddock in a random stratified manner. Quadrants were 50 x 100 cm in size and all the herbage in the quadrant was clipped 5 cm above the soil surface. Four representative pasture samples were obtained by mixing six random pasture samples. During the fourth collection period, paddocks A, B and C were sampled over three consecutive days due to management reasons. Paddock A, B and C were sampled on 25, 27 and 26 June respectively.

3.3.3 Management

The cattle were kept on the pasture and clean drinking water as well as a salt phosphate lick (rumenvite 12P and salt mixed 50:50 on a weight basis) was supplied *ad libitum* for the duration of the study. Animals were weighed every week following an overnight fasting period in order to limit the effect of rumen fill on animal weights.

3.3.4 Parameters measured

Pasture samples were sub-sampled to determine leaf: stem ratio while the rest were dried at 60 °C for 2 days. Dried pasture samples were milled to pass through a sieve with a 1 mm screen and used for chemical analysis. Separate pasture samples were taken to determine pasture availability.

3.3.4.1. Pasture availability

Pasture availability was estimated using an Ellinbank Rising Plate Meter similar to the one described by Bransby *et al*. (1977). Within each paddock five randomly selected quadrants of 0.19845 m^2 in size were used for calibration through linear regression analysis. The pasture height within each quadrant was measured and all the available material 5 cm above ground was removed. The harvested material was oven dried at 70°C for 72 hours to determine the dry mass. Two hundred disk meter readings were taken along four transects of each paddock. Calibration and disk meter readings were taken on a weekly basis. At the start of season 1 pasture availability per ha was estimated from the disk meter calibration equation, Y = 93.97X + 1702.40 (R^2 = 0.49), where Y is the yield of herbage (g DM) per quadrant and X is the mean disc height (cm).

3.3.4.2. Leaf: stem ratio

Leaf and stem material were separated and dried at 60 °C for 2 days. Each component was weighed and the dry matter was determined to calculate leaf: stem ratio. Leaf: stem ratio was calculated as follows:

$$\text{Leaf \%} = \frac{\text{Dry leaf weight}}{\text{Dry leaf weight} + \text{dry stem weight}} \times 100$$

$$\text{Stem \%} = \frac{\text{Dry stem weight}}{\text{Dry leaf weight} + \text{dry stem weight}} \times 100$$

3.3.4.3. Chemical analyses of clipped samples

Clipped pasture samples were analysed at Nutrilab, Department of Animal and Wildlife Sciences, University of Pretoria. Analyses were done to determine:

- dry matter (DM) concentration (934.01 AOAC, 2000),
- neutral detergent fiber (NDF) concentration (Robertson & Van Soest, 1981) on a Tecator Fibrotec System,
- *in vitro* organic matter digestibility (IVOMD) (Tilley & Terry, 1963) using a shaking water bath,
- calcium (Ca) concentration (Giron, 1973) using a Perken-Elmer 5100 Atomic Absorption Spectrometer and
- phosphorous (P) concentration (965.17 AOAC, 2000) using a Specol 1300 Spectrophotometer.

In order to determine the CP concentration (968.06AOAC, 2000) the N concentration was determined using a LECO System model (CHN-1000), a β block digester was used for sample digestion and a Tecator Kjeltec System Model for distillation. The CP concentration was calculated as follows: %CP = %N x 6.25

3.4 SEASON TWO

Climatic factors quantified during season 2 using an automatic weather station is shown in Table 3.3. The minimum and maximum temperatures were 0.3 °C and 31.9 °C respectively.

Table 3.4 Climatic data during season 2

	Temperature (°C)		Wind speed (m/s)		Relative humidity (%)		Solar radiation (W/m2)
	max	min	max	min	max	min	average
27 Aug - 5 Sept	27.7	0.3	18.1	1.6	98.4	7.7	43.6
6 - 12 Sept	31.4	4.0	11.9	1.8	96.1	8.9	46.7
13 - 19 Sept	27.9	4.3	11.5	2.3	94.9	11.2	40.8
20 - 26 Sept	29.0	0.8	12.7	2.4	92.8	7.2	47.1
27 Sept - 3 Oct	30.9	6.4	11.2	2.4	94.6	10.4	42.9
4 - 10 Oct	28.8	6.9	12.7	2.1	97.1	11.2	48.7
11 - 17 Oct	31.9	8.1	14.8	1.2	93.9	11.7	62.2
18 - 24 Oct	30.1	10.2	12.6	2.2	100.0	21.7	56.0
25 - 31 Oct	28.5	10.9	10.7	1.8	98.0	27.2	46.0

Paddock D, E and F (2.5, 2.6 and 4 ha in size) were grazed from 28 August to 6 November 2008. These three paddocks received the same level of fertilization (150 kg N ha^{-1}) in June 2007 during pasture establishment. The irrigation system was not functional during the first part of the season up to 8 September and no rain occurred during this period. From the 8^{th} of September up to the 14^{th} of October the pasture received an average of 20 mm of water (mine waste water irrigation plus rain) per week. The amount of irrigation water was adjusted for the amount of rain water. During the period between 14 October and 11 November the pasture received an average of 30 mm of water.

3.4.1 Treatments

Treatment 4: Paddock D was stocked to achieve a DM pasture allowance of 2% of the total LW of animals.
Treatment 5: Paddock E was stocked to achieve a DM pasture allowance of 2.5% of the total LW of animals.
Treatment 6: Paddock F was stocked to achieve a DM pasture allowance of 3% of the total LW of animals.

3.4.2 Experimental Design

The four rumen cannulated steers (±610 kg) together with the crossbred weaner calves (now weighing 170 kg on average) from the previous season were used in order to apply three grazing pressures (treatments). Paddock D was stocked with one rumen cannulated steer and 71 randomly selected cross bred weaner calves to apply treatment 4. Paddock E was stocked with one rumen cannulated steer and 62 randomly selected cross bred weaner calves to apply treatment 5. Two of the rumen cannulated steers and 66 crossbred weaner calves were stocked in paddock F to apply treatment 6.

Every second week the pasture availability was determined and all the animals were weighed. Pasture growth of 3000 kg over the 70 day grazing period (42 kg $ha^{-1}day^{-1}$) was predicted (personal communication, late Prof. N.F.G. Rethman, Department of plant and soil science, University of Pretoria). This data together were used to make adaptations to the number of animals (stocking rate) in order to keep a constant grazing pressure (Wheeler *et al*., 1973). Weights of these "put-and-take" animals were not used in calculations of ADG. The number of animals in each treatment at a specific time is shown in Table 3.5. The predicted growth used to determine the stocking rate was drastically decreased by the 19^{th} and 25^{th} of September, due to slow pasture growth.Three of the four cannulated steers rotated between paddocks on a weekly basis (treatments) following a 3 x 3 Latin square design (Table 3.6). The fourth cannulated steer was placed in the paddock with the lightest stocking rate (paddock F). Rotation of the cannulated steers was needed to take animal effects into account and provision was made for an adaptation period of four days of each week.

Table 3.5 Animal numbers during season 2

Stocking rate	High	Medium	Low
27 Aug to 12 Sept	72	63	68
12 to 25 Sept	55	57	60
25 Sept to 10 Oct	36	32	44
10 to 24 Oct	13	36	14
24 Oct to 5 Nov	19	18	26

Table 3.6 Experimental design season 2 (Latin square)

	Animal		
Week	a	b	c
1, 4 and 7	Paddock D	Paddock E	Paddock F
2, 5 and 8	Paddock F	Paddock D	Paddock E
3, 6 and 9	Paddock E	Paddock F	Paddock D

Clipped samples of the pasture were taken at the beginning of weeks 3, 6 and 10 (8 Aug, 6 Sept and 10 Oct 2008) from 24 quadrants in each paddock in a random stratified manner. Quadrants were 50 x 100 cm in size and all the herbage in the quadrant clipped 5 cm from the soil surface. Four representative pasture samples were obtained by mixing six random pasture samples.

3.4.3 Dosing of markers

A controlled release device (CRD) containing alkanes C_{32} and C_{36} (YC alkane capsule - Argenta Manufacturing Ltd, Auckland, New Zealand; info@argenta.co.nz) was used to dose animals with markers to calculate intake and digestibility (section 3.4.5.5). On the 29th of August, 26th of September and 24th of October a single CRD was administrated *per os* to the same five animals in each paddock using an applicator supplied by the manufacturer. Faecal grab samples were collected at 9 am and 4 pm from these animals on day 8-14 after administration of the CRD. The CRD was administered four weeks apart in order to insure that C_{32} and C_{36} present in the faeces were only from the CRD administered last. Before the next CRD was administered a faecal grab sample was taken and analysed for C_{32} and C_{36} to confirm that the previous CRD was no longer releasing these markers.

Routine tests by the manufacturer indicated a mean release rate of 219 mg day^{-1} for both C_{32} and C_{36} from the CRD. An experiment was conducted from the 4th to the 18th of November 2008 in order to estimate the actual release rate of the alkanes under the pasture conditions during season 2. The four cannulated steers already adapted to the experimental conditions were used. A long string was attached to the wing of the CRD and the rumen cannula to allow free movement and easy recovery. The CRD was inserted into the rumen at 12 pm on the fourth of November 2008. On 7, 10, 14 and 18 November each CRD was removed, rinsed in cold water, the core length measured at four equidistant points around the circumference and returned to the rumen. To allow core length to be related to elapsed time, the time of day was recorded (Dove *et al.* 2002). The linear regression of payload length vs. elapsed time was used to estimate daily release rates (mm day^{-1}). The density of 67.9 mg mm^{-1} indicated by the manufacturer was used to estimate the daily dosage of C_{32} and C_{36} (mg day^{-1}).

3.4.4 Management

Animals were managed as described for season 1 (see Section 3.3.3) with the exception that animals were weighed every second week without an overnight fast. This change was made for management reasons.

3.4.5 Parameters measured

Pasture samples were sub-sampled to determine leaf stem: ratio while the rest was dried at 60 °C for two days. Dried pasture samples were sub-sampled for chemical analysis and milled to pass through a sieve with a 1 mm screen. The remainder of the dried samples was milled to pass through a sieve with a 2 mm screen and used to determine *in situ* rumen degradability. Separate pasture samples were taken to determine pasture availability.

3.4.5.1. Pasture availability

An Ellinbank Rising Plate Meter was used to estimate pasture availability as described in Section 2.3.2. Calibration and disk meter readings were taken at the start of season 2 pasture availability per ha was estimated form the following disk meter calibration equations:

- in paddock D: $Y = 212.02X - 130.73$ ($R^2 = 0.53$),
- in paddock E: $Y = 254.16X - 578.02$ ($R^2 = 0.84$) and
- in paddock F: $Y = 304.54X - 794.6$ ($R^2 = 0.91$),

where Y is the yield of herbage (g DM) per quadrant and X is the mean disc height (cm). The pasture availability estimates in paddock D, E and F was 3773.7, 3927.4 and 3179.8 (kg DM ha^{-1})

respectively. For timely adaptation of animal numbers the calibration equation of the previous week was used to estimate pasture availability for calculation of stocking rate.

3.4.5.2. Leaf: stem ratio

The leaf: stem ratio were determined in the same manner as in season 1. See Section 2.3.3.1.

3.4.5.3. Chemical analyses of clipped samples

The chemical analyses of clipped samples were determined in the same manner as in season 1. See Section 2.3.3.2.

3.4.5.4. Determination of volatile fatty acids production in the rumen

Rumen fluid was collected during the last three days each week. In order to collect a representative sample, sampling times were varied. For each weak rumen fluid was collected on day 5 at 8 am and 2 pm, on day 6 at 6 am, 12 pm and 6 pm and on day 7 at 10 am and 4 pm to obtain samples representative of every two hours of a day. Rumen fluid was collected with the aid of a syringe fitted with a rumen fluid collection tube (Bar Diamond, Inc.). After each sampling rumen fluid was preserved as follows: 20 ml rumen fluid was preserved with 4 ml 25% H_3PO_4 and frozen. Rumen samples for each animal for each week was mixed and only the representative sample was analyzed for volatile fatty acid (VFA) concentration with gas chromatography (GC).

3.4.5.5. Voluntary intake of weaner calves

Faecal grab samples collected for the seven day period were pooled for each animal. Clipped pasture samples were taken on day 4 of each faecal grab sampling period. These samples were dried at 60 °C, milled to pass through a sieve with a 1 mm screen and analysed for C_{32}, C_{33} and C_{36} alkanes. The alkane analysis was done by Organic Analysis Laboratory, Queenswood, Pretoria, using the procedure described by Dove & Mayes (2006) with some modifications. For extraction 0.5 g faecal or pasture sample, C_{16} as internal standard, 4 ml ethanolic KOH, 4 ml hextane, 0.5 ml H_2O and 1 ml heptane were used. Analysis was done using a Hewlett-Packard GC. Intake was calculated by using the following equation (Dove & Mayes, 2006):

$$\text{Intake} = \frac{\text{dosage rate } C_{32}}{(\text{faecal concentration} C_{32} / \text{faecal concentration} C_{31}) \text{herbage concentration} C_{31} - \text{herbage concentration} C_{32}}$$

Separate calculations were done to estimate digestibility.

$$\text{OM digestibility} = 1 - \frac{C_{31}\text{concentration in herbage OM}}{C_{31}\text{concentration in faeces OM}}$$

$$\text{OM digestibility} = \frac{\text{OM Intake} - \text{OM faecal output}}{\text{OM Intake}}$$

$$\text{OM fecal output (kg OM/day)} = \frac{C_{36}\text{ dosage rate (mg/day)}}{C_{36}\text{concentration in faeces (mg/kg OM)}}$$

3.4.5.6. *In situ* rumen degradability

This trial was conducted at Hatfield Experimental Farm of the University of Pretoria from 27 November to 4 December 2008. During this time, three cannulated Beefmaster steers were fed *Eragrostis* hay: lucerne mix (50:50 on a volume basis) *ad libitum* and water was available *ad libitum*. The animals were adapted to the feed during the first three days of the trial.

The nylon bag technique (Ørskov *et al*., 1980) was used to determine rumen DM degradability within each paddock at the end of season 2 (10 Oct 2008). Nylon bags (pore size 41 µm, 15 mg material per cm^2 of bag) were oven dried at 60 °C for 48 h and cooled down in a desiccator. Five grams of feed were weighed into each nylon bag. Seven bags per paddock were inserted into the rumen of each steer. A nylon stocking was used as accommodation vessel when nylon bags were incubated in the rumen (Cruywagen, 2006). Three bags (one per paddock) were removed from each steer after 2, 4, 6, 8, 12, 24 and 48h of incubation, respectively (Ørskov & McDonald,1979). Upon removal, the bags were hand washed under running water until the water ran clear (approximately 30 min) and placed in a freezer. For each paddock, three control bags, not incubated in the rumen (0 h) were treated similarly to the incubated samples after removal from the rumen. When all the bags were removed the procedure was repeated. At the end of the trial all the bags were thawed, dried at 60 °C for 48 h and after cooling down in a desiccators, it was weighed and the DM (934.01 AOAC, 2000) of the residue was determined. Dry matter disappearance (DMD) was calculated and fitted into the nonlinear model suggested by Ørskov & McDonald (1979).

3.5 STATISTICAL ANALYSIS

Nutritive value, intake and live weight data were statistically analyzed with the Proc GLM model (Statistical Analysis Systems, 2009) to determine the difference between paddocks (treatments) and within paddocks over time. Repeated Measures Analysis of Variance with the Proc GLM model was used for repeated week or periodic measurements. Data of 2, 4 and 2 animals in paddock A, B and C respectively were identified as outliers due to unrealistic weight changes and were excluded from analyses. Starting weight was tested as co-variant for weight data and if significant ($P < 0.05$) it was included. Rumen VFA concentration was analyzed, using a 3 x 3 Latin Square design, by the Proc GLM model to determine influence of treatment, period and animal. Means and standard deviations were calculated and significance of difference ($P < 0.05$) between means was determined by Fischers test (Samuels, 1989).

4 RESULTS AND DISCUSSION

4.1 SEASON 1

At the start of season 1 the results were compared between all paddocks at this point of the trial only the fertilization treatment differed. The remainder of season 1 the two paddocks with the same low stocking density and different N fertilization rates were compared with each other to identify the effect of N fertilization rate on pasture nutritive value and animal performance. The two paddocks receiving the same (low) initial N fertilization rate were compared with each other to evaluate the effect of stocking rate on pasture nutritive value and animal performance.

4.1.1 Pasture Availability

The pasture availability over the course of season 1 is shown in Table 4.1. The review by Peyraud & Astigarraga (1998) found that lowering N fertilization rate results in reduced yield. In this study, the lower rate of N fertilization (LN) was associated with a lower yield compared to the higher rate of N fertilization (HN).

Table 4.1 Pasture availability (kg DM ha^{-1}) over the course of season 1

Treatment	HN#, LS*	LN#, LS*	LN#, HS*
03-Jun	4036.8	3596.4	3490
13-Jun	4439.2	4345.5	2843.8
20-Jun	4110	3497.7	2242.4
27-Jun	3694.8	3208	1998.8
04-Jul	3560.8	3243.5	1837.3
11-Jul	3592.4	3083	1757.1
18-Jul	2939.5	2771.1	1456.5

#HN = High initial N fertilization, LN = low initial N fertilization,

*HS = high stocking rate, LS = low stocking rate

Within paddocks with a low stocking density (LS) an initial increase in pasture availability from 3 to 13 June were found. This indicates that the tall fescue in these paddocks was growing at a rate faster than the rate at which the animals grazed it down. A similar trend in pasture availability was found in the study by Jung & Sahlu (1989). At the high stocking rate (HS) animals removed the plant material at a higher rate than it could be replenished by pasture growth.

From the 13th of June until the end of the trial a general decreasing trend in pasture availability was found. This is probably a result of a decrease in growth rate due to semi-dormant state of tall fescue during winter (Grunow & Rabie, 1985; Klug *et al.,* 2000) and/or increased pasture intake due to an increase in size of the animals (Romney & Gill, 2000). Monthly dry matter (DM) production of tall fescue in May can be two to three times higher compared to July depending on the cultivar and frequency of defoliation (Grunow & Rabie, 1985; Klug *et al.,* 2000).

4.1.2 Leaf: stem ratio

The leaf: stem ratio over the course of season 1 is shown in Table 4.2. At the beginning of the trial the leaf: stem ratio in the two LN paddocks differed significantly ($P < 0.05$) from each other. The HN paddock did not differ significantly ($P > 0.05$) from either of the LN paddocks.

Table 4.2 Leaf: stem ratio over the course of season 1

Treatment	HN#,LS*		LN#,LS*		LN#,HS*		Total mean	SEM[1]
06-Jun	$91:9^{ab}_{1}$	(±2.8)	$94:6^{a}_{1}$	(±1.9)	$90:10^{b}_{1}$	(±1.9)	$91:9_{1}$	1.1
13-Jun	$85:15^{a}_{2}$	(±1.0)	$87:13^{ab}_{2}$	(±2.7)	$89:11^{b}_{12}$	(±2.2)	$85:15_{2}$	1.0
20-Jun	$84:16^{b}_{2}$	(±1.7)	$88:12^{a}_{2}$	(±1.8)	$88:12^{a}_{123}$	(±1.7)	$84:16_{2}$	0.9
25 - 27 Jun	$84:16^{b}_{2}$	(±1.6)	$92:8^{a}_{13}$	(±1.8)	$86:14^{b}_{23}$	(±1.3)	$84:16_{2}$	0.8
02-Jul	$89:11^{a}_{13}$	(±2.2)	$87:13^{a}_{2}$	(±2.8)	$86:14^{a}_{3}$	(±5.4)	$89:11_{2}$	1.9
09-Jul	$87:13^{a}_{23}$	(±3.1)	$88:12^{a}_{2}$	(±1.4)	$89:11^{a}_{12}$	(±4.8)	$87:13_{2}$	1.7
16-Jul	$85:15^{b}_{2}$	(±1.8)	$89:11^{a}_{23}$	(±0.8)	$90:10^{a}_{12}$	(±1.3)	$85:15_{2}$	0.7
Mean	$86:14^{b}$	(±3.2)	$89:11^{a}$	(±3.2)	$88:12^{a}$	(±3.2)	88:12	0.5

#HN = High initial N fertilization, LN = low initial N fertilization,

*HS = high stocking rate, LS = low stocking rate

abcRow means that do not have a common superscript differ ($P < 0.05$)

123Column means that do not have a common subscript differ ($P < 0.05$)

[1]Standard error of the mean

Standard deviation indicated in brackets

Within the two LS paddocks the leaf: stem ratio was significantly ($P < 0.05$) lower at the end of the trial period compared to the beginning. Within the HS paddock the leaf: stem ratio was significantly ($P < 0.05$) lower at 26 June and 2 July compared to the beginning of the trial. Generally the leaf: stem ratio tended to decline as the grazing season progressed. This could be a result of advancing plant maturity (Nordheim-Viken *et al.,* 2009) and due to the selection of leaves by grazing animals (Minson, 1990).

The initial decrease in the leaf: stem ratio within the HS paddock was followed by an increase. As a result no significant ($P > 0.05$) differences were found between the beginning and the end of the trial. The decreasing pasture availability (Table 4.1) would have made selective grazing increasingly difficult and as a result the less digestible stem material was also grazed down. The mean leaf: stem ratio within the HN, LS paddock was significantly (P < 0.05) lower compared to the LN, LS and LN, HS paddocks that did not differ significantly (P > 0.05) from each other.

4.1.3 Dry matter concentration

The pasture dry matter (DM) concentration over the course of season 1 is indicated in Table 4.3. At the start of the season the DM concentration within the LS, LN paddock was significantly (P < 0.05) higher compared to the other two paddocks, which did not differ significantly (P > 0.05) from each other. Within each paddock the DM concentration showed an increasing trend, with significantly (P < 0.05) higher values at the end compared to the start of the trial. This is consistent with the decrease in moisture concentration as plants mature (McDonald *et al.,* 2001).

Table 4.3 Pasture dry matter concentration (g kg^{-1}) over the course of season 1

Treatment	HN$^{\#}$,LS*		LN$^{\#}$,LS*		LN$^{\#}$,HS*		**Total mean**	**SEM[1]**
06-Jun	359.3^{b}_{3}	(±13.5)	438.0^{a}_{4}	(±13.9)	363.3^{b}_{3}	(±10.9)	386.9_{5}	6.4
13-Jun	374.3^{b}_{3}	(±9.2)	444.5^{a}_{4}	(±5.3)	359.9^{c}_{3}	(±10.9)	392.9_{5}	4.4
19-Jun	396.4^{b}_{2}	(±19.4)	447.4^{a}_{4}	(±26.1)	357.2^{c}_{3}	(±14.4)	400.3_{5}	10.3
25 - 27 Jun	392.6^{b}_{23}	(±28.8)	491.8^{a}_{3}	(±32.7)	430.4^{b}_{2}	(±7.5)	438.3_{4}	12.8
02-Jul	416.0^{b}_{2}	(±47.0)	511.0^{a}_{23}	(±39.5)	457.3^{b}_{2}	(±37.0)	461.4_{3}	20.7
09-Jul	463.3^{c}_{1}	(±29.1)	528.8^{b}_{2}	(±34.9)	581.1^{a}_{1}	(±14.5)	524.4_{2}	13.8
16-Jul	473.4^{c}_{1}	(±8.9)	567.5^{b}_{1}	(±11.1)	597.0^{a}_{1}	(±19.6)	546.0_{1}	7.0
Mean	410.8^{c}	(±46.7)	489.9^{a}	(±51.9)	449.4^{b}	(±98.4)	450.0	4.5

$^{\#}$HN = High initial N fertilization, LN = low initial N fertilization,

*HS = high stocking rate, LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

The first frost for the season was observed during the morning of the 26th of June. Considerable browning of the pasture was observed the next day and identified as frost damaged. The only significant (P < 0.05) difference in pasture nutritive value corresponding with the frost damage is the increase in DM concentration (i.e. dehydration) seen in the two LN paddocks. This is probably due to the fact that the frost cause cells to dehydrate and during thawing the cell membranes were damaged, water could not re-enter the cells completely (Salisbury & Ross, 1992). No significant (P > 0.05) difference in DM concentration was observed in the HN paddock from 18 June to 2 Jul.

Frost damage within this paddock was probably less severe. The higher density of plants as well as the higher elevation of this paddock might have resulted in some degree of protection to frost damage. Samples in the two LN paddocks were collected on the 26th and 27th of June. The samples in the HN paddock were collected before the frost (25 Jun) and a week after the frost (9 Jul) during this period some degree of repair might have occurred.

The HN, LS paddock consistently had a significantly ($P < 0.05$) lower DM concentration compared to the LN, LS paddock. Changes in DM concentration in these two paddocks followed the same increasing pattern. The LN, HS paddock showed more drastic increases in DM concentration. As a result in the LN, HS paddock DM concentration was significantly ($P < 0.05$) lower at the first five sampling periods and significantly ($P < 0.05$) higher at the last two sampling periods, compared to the LN, LS. This is probably due to the higher rate of removal of material with a high nutritive value at the high stocking rate.

4.1.4 Crude protein concentration

Pasture CP concentration over the course of season 1 is shown in Table 4.4. It is comparable with the lower range of CP concentration found in literature for tall fescue pasture in literature (67-283 g kg^{-1} DM, Table 2.1).

Table 4.4 Pasture crude protein concentration (g kg^{-1} DM) over the course of season 1

Treatment	HN#,LS*		LN#, LS*		LN#,HS*		Total mean	SEM[1]
06-Jun	124.0^{a}_{1}	(±5.9)	75.4^{c}_{1}	(±3.8)	116.1^{b}_{1}	(±0.9)	105.1_{1}	2.1
13-Jun	111.6^{a}_{2}	(±16.0)	61.0^{b}_{23}	(±3.3)	110.1^{a}_{12}	(±3.1)	94.2_{2}	4.8
20-Jun	102.1^{a}_{23}	(±6.1)	69.0^{b}_{12}	(±11.3)	101.3^{a}_{2}	(±11.2)	90.8_{2}	4.9
25-27 Jun	95.0^{a}_{34}	(±19.2)	61.0^{b}_{23}	(±5.0)	80.0^{a}_{3}	(±3.8)	78.7_{3}	5.8
02-Jul	87.3^{a}_{45}	(±12.3)	55.5^{b}_{3}	(±0.9)	79.5^{a}_{3}	(±4.4)	74.1_{3}	3.8
09-Jul	78.7^{a}_{5}	(±3.3)	55.1^{c}_{3}	(±6.5)	67.9^{b}_{4}	(±4.9)	67.2_{4}	2.5
16-Jul	87.3^{a}_{45}	(±9.0)	56.5^{c}_{3}	(±2.3)	77.0^{b}_{34}	(±3.7)	73.6_{34}	2.9
Mean	98.0^{a}	(±18.0)	61.9^{c}	(±8.8)	90.3^{b}	(±18.2)	83.4	1.5

#HN = High initial N fertilization, LN = low initial N fertilization,

*HS = high stocking rate, LS = low stocking rate

[abc]Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

[1]Standard error of the mean

Standard deviation indicated in brackets

A lower level of N fertilization is expected to result in a lower CP concentration of the pasture (Balasko, 1977; Eck *et al.,* 1981; Peyraud & Astigarraga, 1998; Collins, 1991; Hedtcke *et al.,* 2002; Wolf & Opitz Von Boverfeld, 2003; Burns, 2009). In this study the effect of N fertilization was still evident a year later. At the beginning of the trial the CP concentration for HN was significantly ($P < 0.05$) higher compared to that measured in the other two paddocks which received a lower level of N fertilization at establishment the year before.

The CP concentration found in the LN, LS paddock at the start of the trial was significantly ($P < 0.05$) lower compared to HN, LS paddock as well as the LN, HS paddock. This suggests that the lower CP concentration within this paddock was not only a result of the lower level of N fertilization. Throughout the grazing season a significantly ($P < 0.05$) lower CP concentration were found in the LN, LS paddock compared to the LN, HS paddock. However the change over time in CP concentration was smaller in the LN, LS paddock compared to the other two paddocks. The low CP concentration in the LN, LS could be a result of reduced nutrient uptake due to a higher level of soil compaction (Lipiec & Stępniewski, 1995) restricting root development and nutrient assimilation in this paddock during rehabilitation. Compaction is a serious problem commonly associated with mine soils primarily as the result of the use of heavy earth moving equipment (Mosebi, 2010).

A general decreasing trend in CP concentration was found within each paddock with significantly ($P < 0.05$) higher values found at the start compared to the end of the trial. The total mean CP concentration showed a decreasing trend with significant ($P < 0.05$) differences between samples taken two weeks apart. This reduction in the CP concentration is probably due to the advancing plant maturity (Murray, 1984; Cherney *et al.,* 1993; McDonald *et al.,* 2001; Callow *et al*., 2003; Donaghy *et al*., 2008).

4.1.5 Neutral detergent fiber concentration

Pasture neutral detergent fiber (NDF) concentration (g kg^{-1} DM) over the course of season 1 is presented in Table 4.5. The NDF concentration found in this study is comparable with the lower range found in literature (308-715 g kg^{-1} DM, Table 2.1).

Pasture samples collected at the beginning of the trial, were significantly ($P < 0.05$) higher in NDF concentration for LN, LS paddock compared to the HN, LS paddock and the LN, HS paddock, which did not differ significantly ($P > 0.05$) from each other. Results of this study agree with studies that concluded that N fertilization rate did not affect NDF concentration (Collins, 1991; Peyraud &

Astigarraga, 1998; Hedtcke *et al.,* 2002). Burns (2009) however found higher levels of N fertilization could result in lower levels of NDF.

Table 4.5 Pasture neutral detergent fiber concentration (g kg^{-1} DM) over the course of season 1

Treatment	HN$^{\#}$,LS*		LN$^{\#}$,LS*		LN$^{\#}$,HS*		Total mean	SEM[1]
06-Jun	618.3^{b}_{1}	(±7.1)	647.8^{a}_{1}	(±12.1)	605.4^{b}_{2}	(±10.8)	623.8_{1}	5.1
13-Jun	611.7^{b}_{1}	(±11.6)	622.2^{a}_{2}	(±21.0)	580.3^{b}_{3}	(±27.6)	604.7_{2}	10.6
20-Jun	608.3^{a}_{12}	(±17.2)	628.6^{a}_{12}	(±23.4)	575.5^{b}_{3}	(±15.4)	604.1_{2}	9.5
25-27 Jun	584.7^{b}_{2}	(±17.6)	626.3^{a}_{12}	(±20.2)	566.8^{b}_{3}	(±14.3)	592.6_{2}	8.8
02-Jul	549.7^{b}_{3}	(±12.7)	590.9^{a}_{3}	(±8.3)	562.7^{b}_{3}	(±12.1)	567.8_{3}	5.6
09-Jul	586.0^{a}_{2}	(±23.7)	605.1^{a}_{23}	(±6.0)	586.4^{a}_{23}	(±9.8)	592.5_{2}	7.6
16-Jul	595.9^{b}_{12}	(±34.0)	648.3^{a}_{1}	(±11.9)	638.7^{ab}_{1}	(±16.2)	627.6_{1}	11.4
Mean	593.5^{b}	(±27.8)	624.1^{a}	(±24.3)	588.0^{b}	(±28.7)	601.9	3.3

$^{\#}$HN = High initial N fertilization, LN = low initial N fertilization,

*HS = high stocking rate, LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

Generally the NDF concentration decreased from the start of the trial up to 2 July and then increased towards the end. Within the two LS paddocks, no significant (P > 0.05) differences were found between the first and the last NDF values. However these values were significantly (P < 0.05) higher compared to the samples of 2 July. End NDF values were significantly (P < 0.05) higher than starting values within the LN, HS paddock, with no significant (P > 0.05) differences during the period from 13 June to 9 July. The general trend seen for NDF concentration from the first frost (26 June) onwards corresponds with that expected for maturing plants. With increasing plant maturity the fiber concentration of tall fescue tend to increase (Dugmore *et al.,* 1992; Howard *et al.,* 1992; Cherney *et al.,* 1993; Elizalde *et al.,*1999a, 1999b; Callow *et al*., 2003; Burns *et al*., 2006; Donaghy *et al*., 2008)

Higher NDF values were found in the LN, LS paddock than the HN, LS paddock throughout the sampling season, with significant (P < 0.05) differences at every sampling date except 20 June and 9 July. In the LN, HS paddock, significantly (P < 0.05) lower NDF values compared to the LN, LS paddock were found at the first five sampling dates with no significant (P > 0.05) difference at the last two sampling dates.

The total mean NDF concentration was the highest at the start and end of the season, with significantly ($P < 0.05$) lower values detected for the other dates. The total mean NDF concentration as well as NDF concentration within each paddock showed a decreasing trend up to 2 July and increased from there onwards. The lowest NDF values within each paddock were recorded at 2 July. The mean NDF concentration over the sampling season was significantly higher in the LN, LS paddock compared to the HN, LS and LN, HS paddocks which did not differ significantly ($P > 0.05$) from each other.

4.1.6 Calcium concentration

The calcium (Ca) concentration over the course of season 1 is presented in Table 4.6. The Ca concentration of tall fescue found in this study falls within the range reported in literature (1.9-6.5 g kg^{-1} DM, Table 2.2).

Table 4.6 Calcium concentration (g kg^{-1} DM) over the course of season 1

Treatment	HN#,LS*		LN#,LS*		LN#,HS*		Total mean	SEM[1]
06-Jun	4.3^{b}_{4}	(±0.2)	4.3^{b}_{4}	(±0.2)	5.3^{a}_{3}	(±1.2)	4.6^{5}	0.4
13-Jun	5.5^{a}_{3}	(±0.5)	5.0^{b}_{4}	(±0.4)	5.6^{a}_{3}	(±0.2)	5.4^{4}	0.2
20-Jun	5.3^{a}_{3}	(±0.3)	4.7^{b}_{4}	(±0.2)	5.2^{ab}_{3}	(±0.6)	5.1^{45}	0.2
25 - 27 Jun	5.4^{c}_{3}	(±0.4)	6.6^{a}_{3}	(±0.4)	6.0^{b}_{3}	(±0.2)	6.0^{3}	0.2
02-Jul	5.8^{b}_{23}	(±0.3)	7.0^{a}_{3}	(±0.6)	6.0^{b}_{3}	(±0.5)	6.3^{3}	0.2
09-Jul	6.3^{b}_{2}	(±1.3)	7.9^{a}_{2}	(±0.4)	8.3^{a}_{2}	(±0.4)	7.5^{2}	0.4
16-Jul	7.2^{b}_{1}	(±0.7)	9.9^{a}_{1}	(±0.7)	9.4^{a}_{1}	(±1.0)	8.8^{1}	0.4
Mean	5.7^{b}	(±1.0)	6.5^{a}	(±1.9)	6.5^{a}	(±1.7)	6.2	0.1

#HN = High initial N fertilization, LN = low initial N fertilization,

*HS = high stocking rate, LS = low stocking rate

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

[1]Standard error of the mean

Standard deviation indicated in brackets

Initially the Ca concentration within the HN, LS paddock and LN, LS did not differ significantly ($P > 0.05$) from each other, although their Ca concentrations were significantly ($P < 0.05$) lower compared to the LN, HS paddock. Ca concentration generally increased within each paddock with significantly ($P < 0.05$) higher Ca concentration found at the end compared to the beginning of the trial. These results are in agreement with that of Sinclair *et al.* (2006) who found an increase in Ca concentration of the leaf of irrigated tall fescue over the regrowth period of 60 days (1 Aug to 6 Oct

2000; Australia). The increase in exchangeable Ca in the soil found when using gypsiferous mine waterfor irrigation at Kleinkopje Colliery (Jovanovic *et al.,* 2002) could have played a role in the increase in Ca found in the pasture over the grazing period. The decrease in Ca concentration expected for plants with advancing maturity (Murray, 1984; Bosworth *et al*., 1985; McDonald *et al.,* 2001) was not found in this study.

The mean Ca concentration found within the HN paddock was significantly (P < 0.05) lower compared to that found within either of the LN paddocks which did not differ significantly (P > 0.05) from each other. The Ca concentration of leaf is higher than stem (MacAdam *et al.,* 1997). The significantly (P <0.05) lower mean leaf: stem ratio in the HN paddock compared to the two LN paddocks could be the reason for the lower Ca concentration.

4.1.7 Phosphorous concentration

The phosphorous (P) concentration over the course of season 1 is shown in Table 4.7. The P concentration of tall fescue found in this study falls within the range reported in literature (1.1-3.3 g kg^{-1} DM, Table 2.2). At the start of the trial the P concentration does not differ significantly (P > 0.05) between paddocks.

Table 4.7 Phosphorous concentration (g kg^{-1} DM) over the course of season 1

Treatment	HN#,LS*		LN#,LS*		LN#,HS*		Total mean	SEM[1]
06-Jun	1.7^{a}_{2}	(±0.1)	1.7^{a}_{1}	(±0.2)	2.1^{a}_{12}	(±0.6)	1.8^{23}	0.2
13-Jun	2.1^{a}_{1}	(±0.1)	1.4^{b}_{2}	(±0.1)	2.2^{a}_{1}	(±0.1)	1.9^{12}	0.1
20-Jun	2.0^{a}_{1}	(±0.1)	1.8^{b}_{1}	(±0.1)	2.1^{a}_{12}	(±0.2)	2.0^{1}	0.1
25 - 27 Jun	1.7^{a}_{2}	(±0.2)	1.7^{a}_{1}	(±0.1)	1.9^{a}_{23}	(±0.2)	1.8^{23}	0.1
02-Jul	1.5^{a}_{23}	(±0.1)	1.6^{a}_{12}	(±0.2)	1.9^{a}_{23}	(±0.2)	1.7^{34}	0.1
09-Jul	1.5^{a}_{23}	(±0.1)	1.6^{a}_{12}	(±0.2)	1.7^{a}_{3}	(±0.1)	1.6^{4}	0.1
16-Jul	1.4^{a}_{3}	(±0.1)	1.5^{a}_{12}	(±0.3)	1.7^{a}_{3}	(±0.1)	1.5^{4}	0.1
Mean	1.7^{b}	(±0.3)	1.6^{b}	(±0.2)	1.9^{a}	(±0.3)	1.7	0.04

#HN = High initial N fertilization, LN = low initial N fertilization,

*HS = high stocking rate, LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

A general decreasing trend in P concentration were found with lower P concentrations at the end of the season compared to the start of the trial within all the paddocks and these differences were significant ($P < 0.05$) in the HN, LS and LN, HS paddocks and not in the LN, LS paddock . Results in the HN, LS and LN, HS paddocks does not agree with the study by Sinclair *et al.* (2006) who did not find any changes in P concentration over a 60 day period (1 Aug to 6 Oct 2000; Australia).

With the exception of 13 and 20 June the P concentration did not differ between paddocks. At these dates a significantly ($P < 0.05$) lower P concentration was found in the LN, LS paddock compared to the HN, LS and LN, HS paddocks.

4.1.8 *In vitro* organic matter digestibility

The *in vitro* organic matter digestibility (IVOMD) over the course of season 1 is presented in Table 4.8 and falls in the range reported in literature 324 – 839 g kg^{-1} (Balasko, 1977; Collins & Balasko, 1981; Eck *et al.,* 1981; Bond *et al.,* 1984; Brosworth *et al.,* 1985; Burns *et al.,* 1991, Collins, 1991; Fisher *et al.,* 1991; Cherney *et al.,* 1993; Burns & Chamblee, 2000; Parish *et al.*, 2003a; Volesky *et al.*; 2008; Raesidae *et al.,* 2012). Unlike the NDF concentration, no significant ($P > 0.05$) differences for IVOMD were detected between paddocks at the start of the trial. This is in part due to the large variation found within the LN, LS paddock at this time.

Table 4.8 *In vitro* organic matter digestibility (g kg^{-1} OM) over the course of season 1

Treatment	HN[#],LS*		LN[#],LS*		LN[#],HS*		**Total mean**	**SEM[1]**
06-Jun	615.2^{a}_{4}	(±1.6)	592.3^{a}_{23}	(±43.44)	608.5^{a}_{3}	(±12.3)	605.3_{3}	13
13-Jun	630.8^{a}_{34}	(±34.3)	633.5^{a}_{1}	(±19.20)	669.1^{a}_{1}	(±18.7)	644.5_{2}	12.6
20-Jun	666.8^{ab}_{12}	(±37.8)	623.9^{b}_{12}	(±23.07)	669.0^{a}_{1}	(±15.7)	653.3_{12}	13.6
25-27 Jun	699.5^{a}_{1}	(±14.3)	641.6^{b}_{1}	(±19.95)	665.4^{b}_{1}	(±12.7)	668.9_{1}	8
02-Jul	699.5^{a}_{1}	(±45.1)	630.2^{b}_{1}	(±22.00)	649.3^{ab}_{12}	(±29.0)	659.7_{12}	16.7
09-Jul	661.2^{a}_{23}	(±20.1)	620.2^{b}_{13}	(±16.61)	653.3^{a}_{12}	(±6.4)	644.9_{2}	7.8
16-Jul	643.8^{a}_{24}	(±22.1)	588.9^{b}_{3}	(±12.75)	623.4^{a}_{32}	(±22.2)	618.7_{3}	9.8
Mean	659.5^{a}	(±39.7)	618.7^{b}	(±28.7)	648.3^{a}	(±27.5)	642.2	4.5

[#]HN = High initial N fertilization, LN = low initial N fertilization,

*HS = high stocking rate, LS = low stocking rate

[abc]Row means that do not have a common superscript differ ($P < 0.05$)

[123]Column means that do not have a common subscript differ ($P < 0.05$)

[1]Standard error of the mean

Standard deviation indicated in brackets

Within each paddock, IVOMD at the start and end of the trial did not differ significantly (P > 0.05). The initial increase in digestibility is probably due to removal of less digestible material and the decrease in digestibility is probably a result of the increase in maturity of the pasture. The trend in IVOMD within each paddock was the opposite of that observed for NDF. Results of this study agrees with studies that have shown a reduction in digestibility and increase in fiber as tall fescue matures (Cherney *et al.,* 1993; Elizalde *et al.,*1999a, 1999b;Burns *et al*., 2006; Donaghy *et al*., 2008). In this study the lower digestibility at the end of the trial is also associated with a lower leaf: stem ratio (Nordheim-Viken *et al.,* 2009).

Pasture samples in the LN, LS paddock was significantly (P < 0.05) lower in IVOMD compared to the HN, LS paddock during the last four sampling dates and the LN, HS paddock during the last two sampling dates. The mean IVOMD values were significantly (P < 0.05) lower for the LN, LS paddock compared to the HN, LS and the LN, HS paddocks. Digestibility in the LN, LS paddock was not limited by N fertilization rate or stocking rate.

4.1.9 Animal production

Overall weight data over the course of season 1 is shown in Table 4.9. The overall ADG was significantly (P < 0.05) higher at HN compared to the LN at the same stocking rate. The HS resulted in a significantly (P < 0.05) higher overall ADG compared to the low stocking rate at the same rate of N fertilization. The overall ADG followed the same pattern as the CP concentration of the pasture with significantly (P < 0.05) lower CP concentration in the LN, LS paddock compared to either the HN, LS or LN, HS paddock. The significantly (P < 0.05) lower overall ADG found in the LN, LS paddock was associated with significantly (P < 0.05) lower mean IVDMD and significantly (P < 0.05) higher NDF concentration compared to the HN, LS and LS, HS paddocks.

Table 4.9 Overall weight data over the course of season 1

Treatment	HN#,LS*		LN#,LS*		LN#,HS*		**Total mean**	**SEM**[1]
Starting weight (kg)	135.0_a	(±22.6)	134.8_a	(±22.2)	136.0_a	(±23.7)	135.3	3.47
End weight (kg)	157.0_a	(±23.9)	145.6_c	(±21.5)	149.3_b	(±22.8)	150.6	1.14
ADG (g/day)	482.7_a	(±177.2)	229.1_c	(±167.6)	310.6_b	(±165.4)	340.3	25.4

#HN = High initial N fertilization, LN = low initial N fertilization,

*HS = high stocking rate, LS = low stocking rate

[abc]Row means that do not have a common superscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

Table 4.10 demonstrates the ADG over the course of season 1. Low animal production found during the first week of the study is probably due to the low weight and age of animals used in this study. These early weaned calves needed a longer time to adapt to the pasture conditions. No significant (P > 0.05) differences in ADG were found during the first week of the study. Significantly (P < 0.05) lower ADG in week three compared to week two within each paddock is probably the result of increased cost to maintain core body temperature, due to lower environmental temperatures (Table 3.2). From the second week of the study the ADG in the LN, LS paddock was consistently lower compared to the HN, LS paddock with significant (P < 0.05) differences found during week two, four and six. During the same period the CP concentration within the LN, LS paddock was significantly (P < 0.05) lower compared to the HN, LS paddock (Table 4.4). Similar results were found when comparing the LN, LS and LN and HS paddocks from week two to four, with lower ADG and CP found at the lower stocking rate. This indicate a probability that CP concentration was the main factor limiting production in the LN, LS paddock during this period while pasture availability played a smaller roles. This agrees with the conclusion of Sollenberger & Vanazant (2011) that the nutritive value of a pasture determines the upper limit of ADG.

Table 4.10 Average daily gain (g day^{-1} animal^{-1}) over the course of Season 1

Treatment	HN$^{\#}$,LS*		LN$^{\#}$,LS*		LN$^{\#}$,HS*		Total mean	SEM[1]
3-13 Jun (week 1)	26.2^{a}_{2}	(±672.1)	117.1^{a}_{34}	(±804.6)	58.3^{a}_{2}	(±670.9)	67.2_{3}	73.8
13-20 Jun (week 2)	972.8^{a}_{1}	(±785.2)	484.3^{b}_{12}	(±837.2)	732.1^{ab}_{1}	(±900.9)	729.8_{1}	73.8
20-27 Jun (week 3)	204.1^{a}_{2}	(±825.9)	-24.4^{a}_{34}	(±950.8)	145.8^{a}_{2}	(±968.2)	108.5_{3}	73.8
27 Jun - 4 Jul (week 4)	676.9^{a}_{1}	(±1210.6)	240.4^{b}_{23}	(±1049.5)	544.6^{a}_{1}	(±989.6)	487.3_{2}	73.8
4-11 Jul (week 5)	1006.8^{a}_{1}	(±921.5)	794.4^{ab}_{1}	(±885.3)	571.4^{b}_{1}	(±799.5)	790.9_{1}	73.8
11-18 Jul (week 6)	207.5^{a}_{2}	(±515.8)	-184.7^{b}_{4}	(±446.4)	$-86.3a^{b}_{2}$	(±566.7)	-21.2_{3}	73.8

$^{\#}$HN = High initial N fertilization, LN = low initial N fertilization,

*HS = high stocking rate, LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

The effect of CP concentration of pasture on ADG can be illustrated by the following example. Growing cattle weighing 200 kg will need 0.34 (metabolisable protein) MP per day^{-1} to maintain an ADG of 500g (NRC, 1996). The concentration of CP needed in the diet for beef cattle can be calculated using the following equation: % dietary CP required = [(g MP required per day/ 0.67)/ DM intake per day)] x 100. At an intake of 2% BW (i.e. 2 g DM 100^{-1} kg BW) growing cattle weighing 200 kg will require 12.7% CP in their diet to maintain an ADG of 500 g. At an intake of 3 % BW cattle weighing 200 kg will require 8.5% CP in their diet to maintain an ADG of 500g.

Although mean CP concentration in paddock LN, LS was only 61.9 g kg^{-1}, animals were able to grow at a rate comparable to 500 g during week 2 and 5 in the LN, LS paddock due to selection of material with a higher nutritive value. Burns & Fisher (2011) found higher CP, NDF and digestibility of masticate samples from steers grazing tall fescue compared to material available in the canopy. Coleman & Moore (2003) stated that in fibrous feed, protein and energy are usually the first nutrient to limit animal production, while vitamins and minerals may limit animal production at chronic levels. The ME concentration (MJ kg^{-1} DM) can be calculated by multiplying the digestible organic matter on dry matter (DOMD) with 0.016 (McDonald *et al*., 2001). When using the IVOMD determined in this study the mean energy concentration was 10.55 MJ MEkg^{-1} DM, 9.90MJ MEkg^{-1} DM and 10.37 MJ MEkg^{-1} DM respectively for the HN, LS paddock, the LN, LS paddock and the LN, HS paddock. Thus the lower ADG was also associated with a lower level of energy in the diet.

The ADG in the LN, LS and LN, HS paddocks did not differ significantly (P > 0.05) during the last two weeks of the study. The primary limitation on animal production during this time was low CP and availability within the LN, LS and LN, HS paddocks respectively. When pasture availability is below 2000 kg DM ha^{-1} intake of sheep is reduced (Allden & Whittaker, 1970). From 27 June the pasture availability in the LN, LS paddock was below this level. A significant (P < 0.05) reduction in ADG was found from week five to six within each paddock. The lowest pasture availability and CP concentration as well as high NDF and low *in vitro* limited the animals' ability to consume adequate nutrients for optimum production. The review by Sollenberger & Vanzant (2011) found that forage nutritive value and quantity interact in their effect on animal performance on pasture. They concluded that the nutritive value "sets the upper limit on individual animal performance and determines the forage mass at which the ADG response plateaus".

In the study by Boland and Scaglia (2011) endophyte free tall fescue with a NDF concentration of 617 g kg^{-1} DM and a CP concentration of 122 g kg^{-1} DM sustained an ADG of 820 g day^{-1} for angus-cross steer weaner calves during autumn. Beck *et al.* (2009) found that calves grazing endophyte free tall fescue during winter had an ADG of 1250 g day^{-1} during Dec to Apr 2006 and 780 g day^{-1} during Dec to March 2007. The NDF concentration ranged from 300 to 503 g kg^{-1} DM in 2006 and from 443 – 515 g kg^{-1} DM (Beck *et al.,* 2009). The CP concentration ranged from 21.9 – 25.6% during 2006 and from 20.4 – 30.8% during 2007 (Beck *et al.,* 2009). The ADG of growing heifers grazing stockpiled tall fescue with a CP concentration of 118 g kg^{-1} DM were 590 g day^{-1} in the study by Drewnoski *et al.* (2009). Higher gains found in these studies can be explained by the higher nutritive value of the pasture compared to this study. Hopkins *et al.* (2006) reported ADG of steers grazing Dovey tall fescue during autumn averaged 0.64 kg day^{-1} (nutritive value was not reported).

4.2 SEASON 2

4.2.1 Pasture Availability

The pasture availability over the course of season 2 is presented in Table 4.11. Throughout the season a general decrease in available pasture was found. In the summer grazing trial by Peters *et al.* (1992) tall fescue availability declined as the grazing season progressed. This indicates that the removal of plant material was higher than the growth rate of the grass. Throughout the grazing season the pasture availability at the medium stocking rate (MS) was higher compared to the LS and HS treatments.

Table 4.11 Pasture availability (kg DM ha^{-1}**) over the course of season 2**

Treatment	HS*	MS*	LS*
27-Aug	3773.7	3927.4	3179.8
04-Sept	2255.7	3596.9	2785.0
11-Sept	2082.2	3089.5	2303.0
19-Sept	1596.7	1593.4	2268.0
25-Sept	1743.4	2242.6	2006.2
2-Oct	903.3	2079.8	1186.3
09-Oct	473.1	970.3	502.3
16-Oct	409.9	1031.9	926.6
23-Oct	656.5	743.3	849.1
30-Oct	338.7	833.7	879.5
5-Nov	724.6	1050.5	1003.7

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

4.2.2 Leaf: stem ratio

The leaf: stem ratio over the course of season 2 is indicated in Table 4.12. These values are comparable to the range of leaf: stem ratio (7.9-1.12%) found for tall fescue during spring and summer in the study by Vecellio *et al.* (1995). A significantly ($P < 0.05$) lower leaf: stem ratio at the start of the sampling season was found in the paddock with the MS compared to the other two paddocks which did not differ significantly ($P > 0.05$) from each other. No significant ($P > 0.05$) difference in leaf: stem ratio was found between paddocks on the 6th of Oct. On the 3rd of Nov the paddock with the LS had a significantly ($P < 0.05$) higher leaf: stem ratio compared to the other two paddocks. On the 3rd of Nov the LS and MS paddocks did not differ significantly ($P > 0.05$) from each other in leaf: stem ratio. At the HS a significantly ($P < 0.05$) lower leaf: stem ratio was found on the 3rd of Nov compared to the 8th of Sept, indicating a high rate of removal of the leaf component.

Table 4.12 Leaf: stem ratio over the course of Season 2

Stocking	HS*		MS*		LS*		Total mean	SEM[1]
08-Sept	$86:14^{a}_{1}$	(±3.9)	$81:19^{b}_{2}$	(±4.8)	$88:12^{a}_{1}$	(±2.2)	$85:2_{2}$	1.0
06-Oct	$89:11^{a}_{1}$	(±0.8)	$91:9^{a}_{1}$	(±2.9)	$89:11^{a}_{1}$	(±2.4)	$90:1_{1}$	1.0
3-Nov	$75:25^{b}_{2}$	(±5.6)	$78:22^{b}_{2}$	(±1.3)	$86:14^{a}_{1}$	(±2.5)	$80:2_{3}$	1.0
Mean	$83:17^{b}$	(±7.3)	$83:17^{b}$	(±6.5)	$88:12^{a}$	(±2.4)	85:15	0.9

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

4.2.3 Dry matter concentration

The dry matter (DM) concentration over the course of season 2 is shown in Table 4.13. No significant (P > 0.05) differences in DM concentration were found between paddocks at the first two sampling dates.

Table 4.13 Pasture dry matter concentration (g kg^{-1}) over the course of season 2

Treatment	HS		MS		LS		Total mean	SEM[1]
08-Sept	521.0^{a}_{2}	(±32.8)	464.7^{a}_{2}	(±24.0)	500.2^{a}_{2}	(±64.9)	495.3_{2}	10.9
06-Oct	583.8^{a}_{1}	(±47.4)	582.2^{a}_{1}	(±47.6)	617.4^{a}_{1}	(±42.9)	594.5_{1}	10.9
3-Nov	456.1^{a}_{3}	(±11.1)	404.4^{b}_{3}	(±20.0)	293.4^{c}_{3}	(±12.4)	384.7_{3}	10.9
Mean	520.3^{a}	(±62.5)	483.8^{b}	(±82.6)	470.3^{b}	(±145.8)	491.5	

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

The significant (P < 0.05) increase in DM concentration from the 8th of Sept to the 6th of Oct within each of the paddocks is probably due to water stress when the pivot was broken coupled with high temperatures and slow pasture growth during this period. The DM concentration at the 3rd of Nov within each paddock was significantly ($P < 0.05$) lower than at both the 6th Oct and the 8th of Sept. Physiologically younger plants generally have a lower DM concentration compared to physiologically older plants (McDonald *et al.,* 2001). During the period from the 14th of Oct to the 11th of Nov the pasture received higher amounts of water due to rain. This resulted in a higher percentage of pasture consisting of re-growth (physiologically younger) at the 3rd of Nov with a lower DM concentration.

At the end of the trial the three paddocks differed significantly ($P < 0.05$) from each other in DM concentration. The HS treatment was associated with the highest DM concentration and the LS treatment was associated with the lowest DM concentration. The lower DM concentration is most probably due to a higher proportion of the available pasture consisting of regrowth in the LS paddock compared to the HS paddock.

4.2.4 Crude protein concentration

Pasture CP concentration over the course of season 2 is shown in Table 4.14. Values of CP concentration in this study fall in the range found in literature (67-283 g kg^{-1} DM, Table 2.1). The CP concentration at 8 Sept and 6 Oct did not differ significantly ($P > 0.05$) between paddocks.

Table 4.14 Pasture crude protein concentration (g kg^{-1} DM) over the course of season 2

Treatment	HS		MS		LS		**Total mean**	**SEM**[1]
08-Sept	74.7^{a}_{2}	(±4.1)	80.3^{a}_{3}	(±4.5)	82.8^{a}_{2}	(±13.3)	79.2_{2}	4.5
06-Oct	81.0^{a}_{2}	(±3.3)	103.0^{a}_{2}	(±38.5)	77.8^{a}_{2}	(±9.1)	87.3_{2}	4.5
3-Nov	115.3^{b}_{1}	(±17.4)	136.2^{a}_{1}	(±4.6)	157.5^{a}_{1}	(±8.9)	136.3_{1}	4.5
Mean	90.3^{a}	(±20.9)	106.5^{b}	(±31.5)	106.5^{b}	(±39.3)	101.0	4.5

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

[1]Standard error of the mean

Standard deviation indicated in brackets

Within each paddock a significant ($P < 0.05$) increase in CP concentration was found from the 6th of Oct to the 3rd of Nov. This is probably related to a higher growth rate due the higher amounts of water the pasture received during this time. Beck *et al.* (2006) found an increase in CP with the initiation of spring regrowth. Depending on the tall fescue cultivar used the mean CP concentration ranged from 125 - 219 g kg^{-1} DM in Feb and after an increase in for each cultivar in April the mean CP concentration ranged from 182 - 271 g kg^{-1} (in the Northern hemisphere; Beck *et al.,* 2006).

4.2.5 Neutral detergent fiber concentration

The pasture NDF concentration over the course of season 2 is shown in Table 4.15. The paddocks did not differ significantly (P > 0.05) in NDF concentration at the start of the sampling season. The NDF concentration found in this study is comparable with the lower range found in literature (308-715 g kg-1 DM, Table 2.1).

Table 4.15 Pasture neutral detergent fiber concentration (g kg^{-1}DM) over the course of season 2

Treatment	HS*		MS*		LS*		Total mean	SEM[1]
08-Sept	580.1^{a}_{3}	(±11.9)	577.0^{a}_{3}	(±19.1)	576.7^{a}_{2}	(±7.1)	577.9_{3}	4.2
06-Oct	663.9^{a}_{2}	(±15.6)	638.7^{b}_{2}	(±6.7)	662.1^{a}_{1}	(±6.2)	654.9_{2}	4.2
3-Nov	700.4^{a}_{1}	(±21.4)	698.1^{a}_{1}	(±9.8)	654.7^{b}_{1}	(±21.8)	684.4_{1}	4.2
Mean	648.1^{a}		637.9^{ab}		631.2^{b}		639.1	4.2

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

A significant (P < 0.05) reduction in NDF from the 8th of Sept to the 6th of Oct was found the HS and MS paddock, although no significant (P > 0.05) difference was detected in the with the HS paddock during the same period. From the 6th of Oct to the 3rd of Nov a significant (P<0.05) reduction in NDF concentration was found within all the paddocks. At the end of the sampling season NDF concentration was significantly (P < 0.05) lower within the paddock with the compared to paddocks with HS and MS, which did not differ significantly (P < 0.05) from each other. This is probably due to the significantly higher (P < 0.05) leaf: stem ration found at the low stocking rate compared to the high and medium stocking rate during this time. Leaves generally have a lower NDF concentration compared to stems (Burns *et al.,* 2006).

4.2.6 Calcium concentration

The Ca concentration over the course of season 2 is presented in Table 4.16. The Ca concentration of tall fescue found in this study falls within the range reported in literature (1.9-6.5 g kg^{-1} DM, Table 2.2). At the start and the end of the trial a significantly (P < 0.05) lower Ca concentration was found at the LS compared to the MS and HS. Throughout the trial the Ca concentration in at the LS and MS rate did not differ significantly (P > 0.05) from each other.

Table 4.16 Calcium concentration (g kg^{-1} DM) over the course of season 2

Treatment	HS*		MS*		LS*		Total mean	SEM[1]
08-Aug	8.9^{a}_{2}	(±1.2)	8.5^{a}_{12}	(±0.8)	6.5^{b}_{2}	(±0.7)	8.0^{2}	0.5
06-Sept	14.2^{a}_{1}	(±2.3)	10.8^{a}_{1}	(±3.8)	13.0^{a}_{1}	(±2.5)	12.7^{1}	0.5
10 Oct	6.8^{a}_{2}	(±0.7)	6.7^{a}_{2}	(±0.9)	5.5^{b}_{2}	(±0.1)	6.3^{3}	0.5
Mean	10.0^{a}	(±3.5)	8.6^{ab}	(±2.7)	8.3^{b}	(±3.7)	8.9	0.5

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

Within all the paddocks the Ca concentration increased from Aug to Sept, although significant (P < 0.05) differences were only found at the HS and LS and not at the MS. A significant (P < 0.05) decrease in Ca concentration was found from the 6th of Sept to the 10th of Oct within all the paddocks. This could be related to a decrease in moisture concentration from the 8th of Aug to the 8th Sept due to problems with the irrigation system and no rain. This was followed by an increase in moisture concentration from the 8th of Sept when the irrigations system was repaired and rain occurred. McDonald *et al.* (2001) indicated that the Ca concentration in plants tend to be higher during periods of low soil moisture compared to periods of high soil moisture. This increase in Ca concentration could be related to the increase over time in Ca^{2+} found in soil on rehabilitated mine land when crops were irrigated with gypsiferous mine water (Jovanovic *et al.,* 2002). This could be related to the higher rainfall during this period. Jovanovic *et al.,* (2002) found lower concentrations of Ca^{2+} in the soil during periods of high rainfall. During the period from the 14th of Oct to the 11th of Nov the pasture received higher amounts of water due to rain. The irrigation system was not functional during the first part of the season up to the 8th of Sept and no rain occurred during this period.

4.2.7 Phosphorous concentration

The phosphorous (P) concentration over the course of season 2 is shown in Table 4.17. The P concentration of tall fescue found in this study falls within the range reported in literature (1.1-3.3 g kg^{-1} DM, Table 2.2). At the start and the end of the trial the P concentration in the paddock with the LS were significantly (P < 0.05) higher compared to the paddocks with the HS and MS. No significant (P > 0.05) difference in P concentration was found between the three paddocks in September. Throughout the trial the P concentration in the HS and MS paddocks did not differ significantly (P > 0.05) from each other. Within each of the paddocks the P concentration tended to increase over the period of the trial. Significantly (P < 0.05) higher concentrations of P were found at the end compared to the start of the trial within all the paddocks. Generally the P concentration of tall fescue is higher at a younger physiological stage of maturity (Powell *et al*., 1978; Pendlum *et al.,* 1980; Murray, 1984; Bosworth *et al*., 1985). The higher P concentration at the end of the trial is probably due to new regrowth (younger physiological maturity) present in paddocks compared to the start of the trial (plant material of older physiological maturity). The proportion of regrowth present in the pasture was probably higher at the LS paddock compared to the other paddocks at the end of the trial. This could explain the significantly (P < 0.05) higher P concentration in the LS paddock compared to the other paddocks.

Table 4.17 Phosphorous concentration (g kg^{-1} DM) over the course of season 2

Treatment	HS*		MS*		LS*		**Total mean**	**SEM**[1]
08-Aug	1.4^{b}_{3}	(±0.1)	1.5^{b}_{2}	(±0.1)	1.8^{a}_{2}	(±0.1)	1.6_{3}	0.1
06-Sept	1.9^{a}_{2}	(±0.2)	1.8^{a}_{2}	(±0.7)	2.1^{a}_{2}	(±0.2)	1.9_{2}	0.1
10 Oct	2.7^{b}_{1}	(±0.2)	2.7^{b}_{1}	(±0.2)	3.4^{a}_{1}	(±0.2)	3.0_{1}	0.1
Mean	2.0^{b}	(±0.6)	2.0^{b}	(±0.6)	2.4^{a}	(±0.8)	2.1	0.1

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

4.2.8 *In vitro* organic matter digestibility

The IVOMD over the course of season 2 is shown in Table 4.18. At the beginning of the sampling season IVOMD was significantly (P < 0.05) lower in the LS paddock compared to paddocks with the HS and MS treatment. No significant (P > 0.05) differences were found between the paddocks with paddock HS and MS treatments throughout the sampling season. A significant (P < 0.05) reduction in IVOMD from 8 Sept to 6 Oct was found in all the paddocks corresponding with a significant (P < 0.05) increase in NDF concentration during the same period. This is probably due to the removal of older less digestible material during this period. During this time re-growth was grazed down at a high rate and animals were forced to graze more indigestible parts of the pasture.

Table 4.18 *In vitro* organic matter digestibility (g kg^{-1} OM) over the course of season 2

Treatment	HS*		MS*		Low		Total mean	SEM[1]
08-Sept	756.2^{b}_{1}	(±7.13)	762.2^{b}_{1}	(±11.2)	784.4^{a}_{1}	(±14.3)	767.6_{1}	5.6
06-Oct	683.1^{a}_{2}	(±17.9)	686.7^{a}_{2}	(±25.7)	684.5^{a}_{3}	(±27.3)	689.8_{2}	5.6
3-Nov	690.0^{b}_{2}	(±23.6)	686.4^{b}_{2}	(±4.7)	724.5^{a}_{2}	(±26.4)	700.3_{2}	5.6
Mean	709.7^{b}	(±37.9)	711.8^{b}	(±40.1)	731.1^{a}	(±47.8)	717.5	5.6

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

[abc]Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

Within the MS and HS paddocks no significant (P > 0.05) change IVOMD was found from the 6[th] of Oct to the 3[rd] of Nov regardless of a significant increase in NDF concentration during the same period. This indicates that although the NDF concentration of the pasture was higher at the end of the sampling season, a large portion was digestible. A significant (P < 0.05) increase in IVOMD was found within the LS paddock from 6 Oct to 3 Nov even though the NDF concentration did not change significantly (P > 0.05) during the same period. This is also a result of a higher proportion of the pasture consisting of more digestible regrowth.

4.2.9 *In situ* degradability estimates

In situ DM degradability estimates at the end of season 2 is shown in Table 4.19.

Table 4.19 *In situ* DM degradability (%) estimates at the end of season 2

Stocking	High		Medium		Low		Total mean	SEM[1]
a	14.7^{a}	(±1.0)	15.5^{a}	(±1.7)	11.9^{b}	(±1.9)	14	0.3
b	157.9^{a}	(±100.8)	113.7^{a}	(±55.6)	212.6^{a}	(±173.5)	161.4	60.9
c	0.02^{a}	(±0.02)	0.02^{a}	(±0.02)	0.01^{a}	(±0.01)	0.01	0.01
ED	57.4^{a}	(±7.1)	57.4^{a}	(±6.6)	53.7^{a}	(±5.9)	56.1	2.7

[abc]Row means that do not have a common superscript differ (P < 0.05)

Standard deviation indicated in brackets

a – rapidly soluble fraction (%); *b* – degradable insoluble fraction (%);

c – degradation rate constant of the *b* fraction (/h);

ED – extent of ruminal DM degradation (%)

[1]Standard error of the mean

Good quality (*sic*) forage require roughly 48-60 hours of rumen incubation to reach potential degradability (the sum of the rapidly soluble fraction, *a,* and the degradable insoluble fraction*, b*; Ørskov *et al.,* 1980). In this study the longest incubation time was 48 hours. At this time potential degradability (*a* + *b*) was only reached in some animals and as a result it was calculated to be larger than 100.

At the end of the study the *a* value of the LS paddock was significantly (P < 0.05) lower compared to the MS and HS paddocks. Excluding the *a* value no significant (P > 0.05) differences in degradability estimates was found between paddocks at the end of the trial. Elizalde *et al.* (1999b) studied the effect of plant maturity on *in situ* DM degradability of endophyte-free tall fescue during spring growth. The fractional rate of passage was of 6% per hour was used to calculate ED (extent of ruminal DM degradation). The ED of plants at the tillering stage of maturity was reported to be 65.5% and decreased with age to 60.3% at stem elongation, 60.0% at heading and 38.1% at flowering. The rate of degradation in the rumen for the same periods was 8.6, 7.4, 5.4, 2.7 %/h respectively. The reduction in degradability estimates was associated with an increase of NDF concentration with increasing plant maturity. The NDF concentration (% DM) was reported to be 52.2% at tillering, 54.2% at stem elongation, 60.9% at heading and 66.9% at flowering. In the present study there were no significant (P > 0.05) differences in ED between paddocks even though the NDF concentration found in the low stocking rate paddock was significantly (P < 0.05) lower as compared to the high and medium stocking rate.

The ED calculated for the current study (with a turnover rate of 2% per hour) is comparable with results from the study of Elizalde *et al.* (1999b) of tall fescue at the intermediate stages of maturity. A lower rate of degradation and a higher NDF concentration were found in the current study. The lack of difference in degradability as a result of the higher NDF concentration the current study could be related to the lower turnover rate used to calculate ED compared to the study of Elizalde *et al.* (1999b). Similarly Chaves *et al.* (2006) used a turnover rate of 6% per hour to calculate ED for different fractions of mature tall fescue harvested in the summer. Depending on the plant fraction NDF ranged from 657 (stem) to 506 g kg^{-1} DM (flower) and ED ranged from 46 (stem) to 56% (flower). Again the ED calculated in the current study is higher due to the use of a lower turnover rate in the calculation.

The nutritional value of autumn stockpiled tall fescue was determined by Flores *et al.* (2007). A turnover rate of 2.6% was determined for their basal diet (lucern and maize) in steers. The NDF concentration in pre-grazed forage increased with time from 56.5% to 64.6% and was associated with a reduction of ED from 68.4% to 62.7%. The rate of degradation was not affected by treatment (mean 0.050 h^{-1}). The ED found in the current study was lower, probably due to a higher NDF value.

4.2.10 Alkane concentration and digestibility estimates

The alkane concentration of the pasture over the course of season 2 is shown in Table 4.20. The average C_{31} concentration found in this study is comparable with data published for tall fescue by Bugalho *et al.* (2004), Boadi *et al.* (2002) and the second sampling period of Cortes *et al.* (2005). A higher C_{31} concentration in tall fescue was found in the second period of the study by Cortes *et al*. (2005) and in the study by Piasentier *et al.* (1995).

Table 4.20 Alkane concentration (mg kg^{-1} DM) of the pasture over the course of season 2

Treatment	HS*		MS*		LS*		Total mean	SEM[1]
week 2								
(3-9 Sept)								
C_{32}	16.3^{a}_{12}	(±11.0)	14.0^{a}_{12}	(±2.7)	12.3^{a}_{1}	(±7.5)	14.2_{1}	(±3.1)
C_{31}	247.5^{a}_{1}	(±49.0)	224.0^{a}_{1}	(±64.6)	282.0^{a}_{1}	(±64.8)	251.2_{1}	(±25.2)
week 6								
(30 Sept – 6 Nov)								
C_{32}	11.0^{a}_{2}	(±1.4)	8.5^{a}_{2}	(±1.7)	6.0^{a}_{1}	(±4.1)	8.5_{2}	(±3.1)
C_{31}	188.5^{a}_{12}	(±33.6)	139.3^{a}_{2}	(±11.0)	196.8^{a}_{2}	(±18.1)	174.8_{2}	(±25.2)
week 10								
(28 Nov – 3 Des)								
C_{32}	24.0^{a}_{1}	(±9.2)	19.0^{a}_{1}	(±6.9)	10.0^{b}_{1}	(±1.2)	17.7_{1}	(±3.1)
C_{31}	167.3^{a}_{2}	(±46.7)	186.5^{a}_{12}	(±87.2)	218.0^{a}_{12}	(±27.2)	190.6_{2}	(±25.2)
Mean								
C_{32}	17.1^{b}	(±9.4)	13.8^{ab}	(±6.0)	9.4^{a}	(±5.2)	11.4	(±1.8)
C_{31}	201.1^{ab}	(±53.0)	183.3^{b}	(±67.5)	232.3^{a}	(±53.5)	205.5	(±14.6)

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ for the alkane measured ($P < 0.05$)

[1]Standard error of the mean

Standard deviation indicated in brackets

The C_{31} concentration in the HS paddock declined with time and was significantly ($P < 0.05$) lower at week 10 compared to week 2. Within the MS and LS paddocks the C_{31} concentration showed a significant ($P < 0.05$) reduction from week 2 compared to week 6 and increased towards week 10. No significant ($P > 0.05$) changes in C_{32} concentration were found in the LS paddock. Within the HS and MS paddocks a significant ($P < 0.05$) reduction in C_{32} concentration from week 2 to 6 was followed by a significant (P < 0.05) increase from week 6 to 10. Sampling date has been shown to influence alkane concentration (Zhang *et al*., 2004; Cortes *et al*. 2005).

Table 4.21 Estimated organic matter digestibility (g kg^{-1}) over the course of season 2

Treatment	HS*		MS*		LS*		Total mean	SEM[1]
week 2								
(3-9 Sept)								
C_{31}**	788.6^{a}_{1}	(±64.7)	831.2^{a}_{1}	(±30.1)	718.5^{a}_{1}	(±58.2)	779.4_{1}	25.6
$C_{31}^{\#1}$	824.6^{a}_{1}	(±53.7)	859.9^{a}_{1}	(±25.0)	766.4^{a}_{1}	(±48.4)	816.9_{1}	21.3
C_{36}**	822.2^{a}_{1}	(±45.7)	848.8^{a}_{1}	(±47.4)	744.0^{a}_{1}	(±73.7)	805.0_{1}	21.9
$C_{36}^{\#2}$	831.1^{a}_{1}	(±43.4)	856.4^{a}_{1}	(±45.0)	756.8^{a}_{1}	(±70.0)	814.8_{1}	20.8
week 6								
(30 Sept – 6 Nov)								
C_{31}**	698.7^{a}_{12}	(±34.1)	797.7^{a}_{1}	(±87.9)	685.1^{a}_{1}	(±74.5)	727.2_{12}	25.6
$C_{31}^{\#1}$	749.9^{a}_{12}	(±28.3)	832.1^{a}_{1}	(±72.9)	738.6^{a}_{1}	(±61.9)	773.5_{12}	21.3
C_{36}**	737.7^{a}_{1}	(±40.9)	839.3^{a}_{1}	(±79.1)	734.6^{a}_{1}	(±72.7)	770.5_{12}	21.9
$C_{36}^{\#2}$	750.8^{a}_{1}	(±38.9)	847.4^{a}_{1}	(±75.2)	747.9^{a}_{1}	(±69.0)	782.0_{12}	20.8
week 10								
(28 Nov – 3 Des)								
C_{31}**	632.1^{a}_{2}	(±124.9)	607.2^{a}_{2}	(±116.1)	728.2^{a}_{1}	(±191.2)	655.8_{2}	25.6
$C_{31}^{\#1}$	694.6^{a}_{2}	(±103.7)	674.0^{a}_{2}	(±96.4)	774.4^{a}_{1}	(±158.7)	714.3_{2}	21.3
C_{36}**	718.0^{a}_{1}	(±98.6)	697.0^{a}_{2}	(±84.4)	758.0^{a}_{1}	(±158.1)	724.3_{2}	21.9
$C_{36}^{\#2}$	732.1^{a}_{1}	(±93.7)	712.2^{a}_{2}	(±80.1)	770.1^{a}_{1}	(±150.2)	738.1_{2}	20.8
Mean								
C_{31}**	706.5^{a}	(±102.0)	745.4^{a}	(±129.4)	710.6^{a}	(±115.6)	720.8	25.6
$C_{31}^{\#1}$	756.4^{a}	(±84.6)	788.6^{a}	(±107.4)	759.8^{a}	(±95.9)	768.3	21.3
C_{36}**	759.3^{a}	(±77.8)	795.1^{a}	(±98.1)	745.5^{a}	(±101.5)	766.6	21.9
$C_{36}^{\#2}$	771.3^{a}	(±73.9)	805.3^{a}	(±93.2)	758.3^{a}	(±96.4)	738.1	20.8

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

**Assuming a faecal recovery of 1.0

[#1]Assuming a faecal recovery of 0.83 (mean from Piasentier *et al*., 1995 and Dove *et al.,* 2002)

[#2]Assuming a faecal recovery of 0.95 (indicated by Dove & Mayes 2006)

[abc]Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means for a method that do not have a common subscript differ (P < 0.05)

Standard deviation indicated in brackets

[1]Standard error of the mean

Estimated organic matter digestibility over the course of season 2 is reported in Table 4.21. Differences between methods of calculation within each paddock and each sampling date were evaluated statistically and did not show significant differences (P < 0.05). The variation within a paddock for a specific sampling time was lower when faecal recovery was taken into account. No significant (P >0.05) differences in OM digestibility was found between paddocks within any of the sampling periods (Table 3.20).

No significant (P > 0.05) changes in OM digestibility was found in the LS paddock. The IVOMD within this paddock showed significant (P < 0.05) differences between sampling dates (Table 4.18). This indicates that animals grazing this paddock were able to select plant material with a higher digestibility due to the low grazing pressure.

At the HS a significantly (P < 0.05) lower OM digestibility was found at week 10 compared to the other sampling periods when C_{31} were used to estimate digestibility. Although the same trend was seen when C_{36} were used to estimate digestibility, differences were not significant (P > 0.05). The IVOMD within this paddock was significantly (P < 0.05) lower during week 6 and week 10 compared to week 2. This indicates that during week 6 animals were still able to select for plant material with a higher digestibility, but during week 10 the reduction in pasture availability prevented the selection of higher quality material.

Digestibility estimates using alkanes was generally higher than IVOMD. Both IVOMD and digestibility estimated using alkanes were higher than effective DM degradability.

4.2.11 Voluntary intake

Table 4.22 shows the pasture intake of weaner calves grazing tall fescue over the course of season 2. In the study by Burns *et al.* (1991) the estimated DM intake of steers grazing endophyte free tall fescue during spring was 3.41kg 100^{-1} kg BW day^{-1}.

At week 2 no significant (P > 0.05) differences in intake were detected between HS and MS treatments. Intake at the LS was significantly (P < 0.05) lower compared to the MS and HS. In the MS paddock a significantly (P < 0.05) higher intake was found during week 6 compared to HS and LS paddocks, which did not differ significantly (P < 0.05) from each other.

Intake in the MS paddock at week 10 did not differ significantly (P > 0.05) from either the HS or LS paddock. During week 10 intakes were significantly (P < 0.05) higher at the LS compared to the HS. Higher intakes are usually associated with higher quality (*sic*; Minson, 1990; Allen, 1996) and quantity (Jung & Shalu, 1989; Dalley *et al*., 1999) of available plant material. This was not the case in this study. Low intakes were associated with the low stocking rate (i.e. high availability) probably as a result of the extremely low DM (293.4 g kg^{-1}, Table 4.13) concentration at week ten. Studies have shown a lower DM intake when herbage are lower in DM concentration (Kenney *et al.,* 1984; Butris & Phillips, 1987; Phillips *et al.,* 1991 Cabrera Estrada *et al.,* 2003, 2004). Kenney *et al.* (1984) showed that DM intake was reduced due to a high concentration of water when DM concentration was lower than 400 g kg^{-1}, i.e. water concentration higher than 600 g kg^{-1}.

Table 4.22 Pasture intake of weaner calves grazing tall fescue over the course of season 2

Treatment	HS*		MS*		LS*		**Total mean**	**SEM**[1]
week 2								
(3-9 Sept)								
g DM/kg $W^{0.75}$	100.8^{a}_{1}	(±20.0)	105.5^{a}_{1}	(±12.8)	74.8^{b}_{1}	(±11.0)	93.7_{1}	3.1
g OM/kg $W^{0.75}$	90.2^{a}_{1}	(±17.9)	94.4^{a}_{1}	(±11.4)	67.4^{b}_{1}	(±9.9)	84.0_{1}	2.8
g DM/100kg BW	2.8^{a}_{1}	(±0.6)	2.9^{a}_{1}	(±0.4)	2.1^{b}_{1}	(±0.3)	2.6_{1}	0.1
g digestible OM kg-^{1} $W^{0.75}$	68.2^{a}_{1}	(±13.5)	72.0^{a}_{1}	(±8.7)	52.8^{b}_{1}	(±7.8)	64.3_{1}	2.1
week 6								
(30 Sept – 6 Oct)								
g DM/kg $W^{0.75}$	61.6^{b}_{2}	(±6.0)	104.4^{a}_{1}	(±16.8)	67.2^{b}_{12}	(±10.4)	77.7_{2}	3.1
g OM/kg $W^{0.75}$	54.0^{b}_{3}	(±5.3)	91.9^{a}_{1}	(±14.8)	59.0^{b}_{12}	(±9.2)	86.3_{2}	2.8
g DM/100kg BW	1.8^{b}_{2}	(±0.2)	2.9^{a}_{1}	(±0.5)	1.9^{b}_{12}	(±0.3)	2.2_{2}	0.1
g digestible OM kg-^{1} $W^{0.75}$	36.9^{b}_{2}	(±3.6)	63.1^{a}_{1}	(±10.2)	40.4^{b}_{2}	(±6.3)	46.8_{2}	2.1
week 10								
(28 Oct – 3 Nov)								
g DM/kg $W^{0.75}$	76.2^{a}_{2}	(±10.5)	62.2^{ab}_{2}	(±10.5)	56.1^{b}_{2}	(±5.6)	64.8_{3}	3.1
g OM/kg $W^{0.75}$	68.3^{a}_{2}	(±9.4)	55.0^{ab}_{2}	(±9.3)	49.4^{b}_{2}	(±4.9)	57.6_{3}	2.8
g DM/100kg BW	2.1^{a}_{2}	(±0.3)	1.7^{ab}_{2}	(±0.3)	1.5^{b}_{2}	(±0.2)	1.8_{3}	0.1
g digestible OM kg-^{1} $W^{0.75}$	47.1^{a}_{2}	(±6.5)	37.8^{ab}_{2}	(±6.4)	35.8^{b}_{2}	(±3.5)	40.2_{3}	2.1
mean								
g DM/kg $W^{0.75}$	79.5^{b}	(±20.9)	90.7^{a}	(±24.4)	66.0^{c}	(±11.8)	78.8	3.1
g OM/kg $W^{0.75}$	70.8^{b}	(±19)	80.5^{a}	(±21.7)	58.6^{c}	(±10.8)	70.0	2.8
g DM/100kg BW	2.2^{b}	(±063)	2.5^{a}	(±0.7)	1.8^{c}	(±0.3)	2.2	0.1
g digestible OM kg-^{1} $W^{0.75}$	50.7^{b}	(±15.58)	57.6^{a}	(±17.0)	43.0^{c}	(±9.4)	50.5	2.1

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ for the parameter measured (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

At the HS, intake decreased significantly (P < 0.05) from week 2 compared to week 6. Intake at the HS showed an increasing trend from week 6 to week 10, with significant differences only detected for intake expressed as g OM kg^{-1} $W^{0.75}$. No significant (P > 0.05) differences in intake were detected from week 2 to 6 at the MS. From week 6 to week 10 a significant (P < 0.05) reduction in intake was found at the MS.

Within each paddock significantly (P < 0.05) lower intakes were found at the end compared to the start of the sampling season. This could in part be a result of the increase in NDF concentration found in forage available within each paddock (Table 4.15). Significantly (P < 0.05) higher NDF concentrations were found at 3 Nov compared to 8 Sept. Reid *et al*. (1988) found a correlation coefficient of 0.41 between the NDF concentration in forage fed and the DM intake of cattle.

Intakes found in this study fall in the range of intakes (2.7-1.8 kg $100kg^{-1}$ BW day^{-1}) measured by Stewart *et al.* (2008) for steers grazing endophyte free tall fescue between the end of spring to the start of autumn. Burns *et al.* (1991) found higher intakes (3.41 kg $100kg^{-1}$ BW day^{-1}) by steers grazing endophyte free pasture during spring.

4.2.12 Rumen parameters

Molar proportions of VFA, total VFA (m*M*) and pH over the course of season 2 is indicated in Table 4.23. Throughout sampling season 2, no significant (P > 0.05) differences were found in rumen VFA concentration and rumen pH between paddocks.

In the study by McCracken *et al.* (1993) the VFA concentrations of steers grazing tall fescue were measured. The total VFA concentration (111.1-134.4 m*M*) as well as the molar proportions of proprionate (21.9 – 28.8 mol 100^{-1} mol) were higher and that of acetate (57.1 – 65.2 mol 100^{-1} mol) were lower compared to this study. The proportions of butarate (10.3 – 11.3 mol 100^{-1} mol), and isobuterate (0.7 – 1.0 mol/100 mol) and were comparable to this study.

Langlands & Sanson (1976) found that an increase of available green forage (temperate grass) generally resulted in a decline in the proportion of acetic acid and an increase in the proportions of other acids in cattle, while the total concentration of VFA decreased. Similarly in this study the higher pasture availability during 2 – 22 Sept was associated with significantly (P < 0.05) higher total VFA production compared to 14 Oct – 3 Nov within the paddocks receiving the high stocking rate. The total VFA concentration within the medium and low stocking rates did not differ significantly (P > 0.05) between the period from 2 – 22 Sept and the period from 14 Oct – 3 Nov.

The proportion of propionate was significantly (P < 0.05) lower and acetate significantly (P < 0.05) higher at 2 – 22 Sept compared to 14 Oct – 3 Nov within the HS and MS paddocks, while butyrate concentration did not differ significantly (P > 0.05) between time periods. McCracken *et al.* (1993) also found significantly (P < 0.05) higher proportions of acetate and significantly (P < 0.05) lower proportions of propionate at a two week grazing period during the end of spring compared to a two week grazing period at the start of summer, with no significant (P > 0.05) differences in proportions of butyrate between these two periods. McDonald *et al.* (2001) indicated that the proportion of acetic acid tends to be higher and the proportion of propionic acid lower in mature fibrous forage compared less mature forage. Similarly in this study the significantly (P < 0.05) higher NDF concentration and the significantly ($P < 0.05$) lower IVOMD found at the end of the trial compared to the start was generally associated with significantly ($P < 0.05$) higher proportions of acetate and significantly ($P < 0.05$) lower proportions of propionate.

Table 4.23 Molar proportions of volatile fatty acids, total volatile fatty acids (m*M*) and pH over the course of season 2

Treatment	HS*		MS*		LS*		**Total mean**	**SEM**[1]
2 - 22 Sept								
Acetate	70.3^{a}_{2}	(±2.5)	69.6^{a}_{2}	(±1.5)	69.9^{a}_{2}	(±0.8)	69.9_{2}	0.4
Proprionate	17.2^{a}_{1}	(±1.6)	18.0^{a}_{1}	(±0.5)	17.7^{a}_{1}	(±0.5)	17.7_{1}	0.3
Butyrate	11.2^{a}_{1}	(±0.8)	11.0^{a}_{1}	(±1.2)	11.0^{a}_{1}	(±0.3)	11.1_{1}	0.2
Isobuterate	0.5^{a}_{3}	(±0.1)	0.6^{a}_{3}	(±0.1)	0.5^{a}_{3}	(±0.1)	0.5_{3}	0.1
Valerate	0.8^{a}_{1}	(±0.2)	0.8^{a}_{1}	(±0.1)	0.9^{a}_{1}	(±0.2)	0.8_{1}	0
Total VFA	81.6^{a}_{1}	(±13.2)	80.6^{a}_{1}	(±5.6)	76.0^{a}_{1}	(±4.1)	79.4_{1}	2.6
pH	6.6^{a}_{1}	(±0.1)	6.6^{a}_{1}	(±0.1)	6.6^{a}_{1}	(±0.1)	6.6_{1}	0.1
23 Sept - 13 Oct								
Acetate	74.1^{a}_{1}	(±0.7)	74.5^{a}_{1}	(±0.7)	72.2^{a}_{1}	(±2.6)	73.6_{1}	0.4
Proprionate	14.7^{b}_{2}	(±0.7)	14.5^{b}_{2}	(±0.6)	16.4^{a}_{2}	(±1.8)	15.2_{2}	0.3
Butyrate	9.8^{a}_{1}	(±0.3)	9.6^{a}_{1}	(±0.6)	9.8^{a}_{1}	(±0.4)	9.7_{2}	0.2
Isobuterate	0.8^{a}_{2}	(±0.2)	0.8^{a}_{2}	(±0.1)	0.9^{a}_{2}	(±0.2)	0.8_{2}	0.1
Valerate	0.6^{a}_{1}	(±0.0)	0.6^{a}_{1}	(±0.1)	0.7^{a}_{1}	(±0.3)	0.6_{2}	0
Total VFA	68.5^{a}_{12}	(±11.4)	60.5^{a}_{2}	(±5.1)	71.9^{a}_{1}	(±5.0)	66.9_{2}	2.6
pH	6.5^{a}_{1}	(±0.2)	6.7^{a}_{1}	(±0.2)	6.6^{a}_{1}	(±0.2)	6.7_{1}	0.1
14 Oct – 3 Nov								
Acetate	73.5^{a}_{1}	(±1.0)	73.1^{a}_{1}	(±1.5)	72.0^{a}_{12}	(±3.6)	72.9_{1}	0.4
Proprionate	15.0^{a}_{2}	(±1.1)	15.6^{a}_{2}	(±1.0)	15.3^{a}_{2}	(±2.0)	15.3_{2}	0.3
Butyrate	9.7^{a}_{1}	(±0.5)	9.6^{a}_{1}	(±0.1)	10.7^{a}_{1}	(±1.3)	10.0_{2}	0.2
Isobuterate	1.1^{a}_{1}	(±0.1)	1.0^{a}_{1}	(±0.3)	1.2^{a}_{1}	(±0.3)	1.1_{1}	0.1
Valerate	0.7^{a}_{12}	(±0.1)	0.7^{a}_{1}	(±0.2)	0.8^{a}_{1}	(±0.2)	0.7_{1}	0
Total VFA	66.7^{a}_{2}	(±13.1)	70.8^{a}_{12}	(±7.0)	67.5^{a}_{1}	(±14.3)	68.3_{2}	2.6
pH	6.8^{a}_{1}	(±0.2)	6.6^{a}_{1}	(±0.2)	6.7^{a}_{1}	(±0.3)	6.7_{1}	0.1
mean								
Acetate	72.6^{a}	(±2.2)	72.4^{a}	(±2.5)	71.4^{a}	(±2.5)	72.1	0.4
Proprionate	15.6^{a}	(±1.5)	16.0^{a}	(±1.7)	16.5^{a}	(±1.7)	16.0	0.3
Butyrate	10.2^{a}	(±0.7)	10.1^{a}	(±1.0)	10.5^{a}	(±0.7)	10.3	0.2
Isobuterate	0.8^{a}	(±0.3)	0.8^{a}	(±0.2)	0.8^{a}	(±0.4)	0.8	0.1
Valerate	0.7^{a}	(±0.2)	0.7^{a}	(±0.2)	0.8^{a}	(±0.2)	0.7	0
Total VFA	72.3^{a}	(±13.0)	70.6^{a}	(±10.1)	71.8^{a}	(±8.7)	71.6	2.6
pH	6.8^{a}	(±0.2)	6.6^{a}	(±0.1)	6.7^{a}	(±0.2)	6.7	0.1

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

[abc]Row means that do not have a common superscript differ for the same parameter ($P < 0.05$)

[1]Standard error of the mean

Standard deviation indicated in brackets

No significant (P > 0.05) differences in pH were found between time periods or paddocks throughout the study. The pH in the rumen found in the present study fall in the range (5.5-6.5) found in the rumen under normal conditions (McDonald *et al*., 2001). The pH levels measured in this study were higher compared to the study by McCracken *et al.* (1993) were the ruminal pH of steers grazing tall fescue ranged from 5.6 to 6.0.

4.2.13 Animal production

Two-weekly ADG over the course of season 2 is shown in Table 4.24. From 28 Aug to 12 Sept the ADG at the LS were significantly (P < 0.05) lower compared to the MS and HS. This could be due to the significantly (P < 0.05) lower intake found at the LS during 3-9 Sept (Table 4.22).

Table 4.24 Two-weekly average daily gain (g day^{-1}) over the course of season 2

Treatment	HS*		MS*		LS*		**Total mean**	**SEM**[1]
28 Aug - 12 Sept	489.6^{ab}_{1}	(±619.8)	819.4^{a}_{1}	(±774.1)	294.6^{b}_{12}	(±599.7)	534.6_{1}	96.9
12 - 25 Sept	-359.0^{a}_{23}	(±452.5)	-282.1^{a}_{3}	(±413.8)	-154.8^{a}_{2}	(±444.5)	-265.0_{3}	96.9
25 Sept - 10 Oct	-483.3^{b}_{3}	(±469.8)	-285.2^{ab}_{3}	(±281.7)	71.4^{a}_{12}	(±875.7)	-232.4_{3}	96.9
10 - 24 Oct	95.2^{a}_{12}	(±967.6)	198.4^{a}_{2}	(±325.5)	112.2^{a}_{12}	(±1090.0)	135.3_{2}	96.9
24 Oct - 7 Nov	544.4^{a}_{1}	(±1011.8)	-48.1^{b}_{23}	(±291.8)	485.7^{a}_{1}	(±339.4)	327.3_{12}	96.9

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

The main energy source for ruminants is VFA and generally accounts for 50-75% of digested energy (Faverdin, 1999). The reduction in total VFA concentration (Table 4.32) from the period between 2-22 Sept and 23 Sept to 13 Oct at the high stocking rate indicated a reduction in energy available to the animal for maintenance and production. This could be part of the reason for weight losses found between 12 Sept and 10 Oct at the low stocking rate.

Losses in body weight during the period from 12 Sept to 24 Oct were most probably due to a limitation in protein intake. High intake at the high stocking rate compensated to some degree for the low CP concentration of the pasture during 28 Aug - 12 Sept. The improvement in ADG during the week from 10 to 24 October is probably due to the significant (P < 0.05) increase in CP concentration from 6 Oct to 3 Nov.

Overall weight data was corrected for starting weight and did not show any significant (P > 0.05) differences between paddocks (Table 3.24). No significant differences (P > 0.05) in overall ADG were found between treatments due to the high level of variation within a treatment. Hopkins *et al.* (2006) reported ADG of steers grazing Dovey tall fescue during spring averaged 0.64 kg day^{-1} (nutritive value not reported). Burns & Fisher (2011) found an ADG of 0.95kg day^{-1} for steers grazing tall fescue during spring, with 186-207 g CP kg^{-1} OM and 594-625 g NDF kg^{-1} OM.

Table 3.24 Overall weight data over the course of season 2

Treatment	HS*		MS*		LS*		**Mean**	**SEM[1]**
Starting weight (kg)	165.5[a]	(±17.7)	160.4[a]	(±28.3)	165.0[a]	(±23.1)	163.3	6.4
End weight (kg)	169.5[a]	(±19.1)	167.7[a]	(±22.9)	177.6[a]	(±19.1)	171.3	5.5
ADG (g day^{-1})	54.8[a]	(±156.9)	98.9[a]	(±213.1)	173.2[a]	(±114.1)	110.5	45.4

*HS = high stocking rate, MS = medium stocking rate LS = low stocking rate

[abc]Row means that do not have a common superscript differ (P < 0.05)

[1]Standard error of the mean

Standard deviation indicated in brackets

5 CONCLUSION

A higher level of N fertilization at pasture establishment (300 kg N ha^{-1}) resulted in a significantly (P < 0.05) higher CP concentration a year later compared to the lower level of N fertilization (150 kg N ha^{-1}). Level of N fertilization at pasture establishment did not have a significant (P > 0.05) effect on other measurements of pasture nutritive value (NDF, Ca, P and IVOMD). This higher CP concentration together with a higher pasture availability per ha with the higher level of N fertilization at pasture establishment, resulted in a significantly (P < 0.05) higher ADG. This indicate that level of N fertilization at pasture establishment on rehabilitated mine land will have implications over the long term regarding pasture nutritive value (CP concentration), DM production (yield) and animal production.

Lower animal production per ha and a significantly (P < 0.05) lower ADG were found at the LN, LS compared to the LN, HS in season 1. This was associated with a significantly (P < 0.05) lower nutritive value (lower CP, lower mean IVOMD and lower mean NDF) in the LN, LS compared to the LN, HS paddock. In this case animal production was primarily limited by pasture nutritive value and not quantity of available forage. At the end of season 1, animals were losing weight and pasture availability was limiting animal production at the high stocking rate. Thus the lower stocking rate is recommended. Protein supplementation should be considered when the nutrient concentration in pasture starts to limit animal production. Alternatively pastures can be used for animals with lower nutrient requirements for, i.e. maintenance.

During season 2 the average nutritive value within the LS paddock was significantly (P < 0.05) higher (higher CP, leaf: stem ratio and IVOMD, with a lower NDF) compared to the HS paddock. In the HS paddock, forage with a high nutritive value was removed by animals at a higher rate, resulting in a higher proportion of the pasture consisting of younger plant material at the LS. The low CP concentration found for tall fescue during September may limit production under low intake conditions (see p39). Irrespective of the calculation used, digestibility calculated by the alkane method did not differ significantly (P > 0.05) between treatments at any time period. The alkane method was a relative easy method to determine intake of grazing cattle. Due to significant (P < 0.05) changes in alkane concentration between periods, it is essential to know the alkane concentration during the intake determination period. Due to the intake determination it was possible to identify the cause for a significantly lower (P < 0.05) ADG at the LS during the first week. This is a result of a significantly (P < 0.05) lower intake. The average intake in the MS paddock was significantly (P < 0.05) higher than the average for the other paddocks. The paddock with the MS was managed to supply a pasture allowance of 2.5% BW. The intake over the spring season was 2.2 % BW. The medium grazing pressure supplied sufficient plant material without resulting in large accumulation of plant material.

6 CRITICAL EVALUATION

If any recommendations were to be made regarding N fertilization level at pasture establishment on rehabilitated mine land, further research is needed. The effect of intermediate levels (between 150 and 300 kg N ha^{-1}) of fertilization should also be considered. Further research is needed to determine the economic and environmental effects of a higher level of fertilization at pasture establishment on rehabilitated mine land.

Accurate determinations of the ideal stocking rate will need to take into account the sustainability of pasture DM production. The effect of a stocking rate on the future production potential of the pasture will need to be taken into account. The estimation of gain per hectare will give an indication of the economical stocking rate. This will require at least three replications for each stocking rate in a single trial.

At the end of the autumn grazing season the nutrient intake of cattle were not sufficient to sustain growth in the LN, LS and LN, HS paddocks. Estimates of intake during this season could have indicated at what point pasture availability became limiting.

During the spring season pasture did not grow at the predicted rate and animal numbers needed to be reduced every second week. Irrigation problems before the spring season of the trial, most probably affected the growth potential of the pasture. It is critical that conditions affecting the trial should be controlled as far as possible. Irrigation equipment should be kept in a working condition at all times. Continuous estimation of growth rate for the trial conditions together with implementation of these values in determination of stocking rate will be ideal.

The recovery of alkanes in cattle shows large variations in the literature. The use of recovery rates from the literature could have led to inaccurate digestibility estimates in this study. Digestibility estimates with the alkane method would be more accurate if the recovery rate of the alkanes were determined during this trail to suit the conditions of this trail.

REFERENCES

ALLDEN, W.G., & WHITTAKER, I.A.McD., 1970. The determinants of herbage intake by grazing sheep: the interrelationship of factors influencing herbage intake and availability. *Aust. J. Agr. Res.* 21(5):755-766.

ALLEN, M.S,. 1996. Physical constraints on voluntary intake of forages by ruminants. *J. Anim. Sci.* 74(12):3063-3075.

ALLISON, C.D., 1985. Factors affecting forage intake by range ruminants: a review. *J. Range Manage.* 38(4):305-311.

ALSHAMMARY, S.F., QIAN, Y.L. & WALLNER, S.J., 2004. Growth response of four turf grass species to salinity. *Agr. Water Manage.* 66(2):97-111.

AOAC International., 2000. *Official methods of analysis of AOAC International.* 17th edition. William Horwitz, W. (ed.) Volume I. Gaithersburg, Maryland: Association of Official Analytical Chemists International.

ANNANDALE, J.G., JOVANOVIC, N.Z., PRETORIUS, J.J.B., LORENTZ, S.A., RETHMANN, F.G. & TANNER, P.D., 2001. Gypsiferous mine water use in irrigation on rehabilitated open-cast mine land: crop production, soil water and salt balance. *Ecol. Eng.* 17(2-3):153-164.

ANNANDALE, J.G., JOVANOVIC, N.Z., HODGSON, F.D.I., USHER, B.M., AKEN, M.E., VAN DER WESTHUIZEN, A.M., BRISTOW, K.L. & STEYN, J.M., 2006. Prediction of the environmental impact and sustainability of large-scale irrigation with gypsiferous mine water on groundwater resources. *Water SA* 32(1):21-28.

ASAY, K.H., JENSEN, K.B., WALDRON, B.L., HAN, G., JOHNSON, D.A. & MONACOT, A., 2002. Forage quality of tall fescue across an irrigation gradient. *Agron. J.* 94(6):1337-1343.

BACON, C.W., 1995. Toxic endophyte-infected tall fescue and range grasses: historic perspectives. *J. Anim. Sci.* 73(3):861-870.

BAGLEY, C.P., FONTENOT, J.P., BLASER, R.E. & WEBB, K.E., 1983. Nutritional value and voluntary intake of tall fescue (*Festuca arundinacea* Schreb.) fed to sheep. *J. Anim. Sci.* 57(6):1383-1391.

BALASCO, J.A., 1977. Effects of N, P, and K fertilization on yield and quality of tall fescue forage in winter. *Agron. J.* 69(3):425-428.

BARRE, P., EMILE, J.C., BERTIN, M., SURAULT, F., GHESQUIÈRE, M. & HAZARD, L., 2006. Morphological characteristics of perennial ryegrass leaves that influence short-term intake in dairy cows. *Agron. J.* 98(4):978-985.

BEATY, E.R. & ENGEL, J.L., 1980. Forage quality measurements and forage research: a review, critique and interpretation. *J. Range Manage.* 33(1):49-54.

BECK, P.A., STEWART, C.B., GUNTER, S.A. & SINGH, D., 2009. Evaluation of tall fescues for stocker cattle in the gulf coastal plain. *Prof. Anim. Sci.* 25(5):569-579.

BECONI, M.G., HOWARD., M.D., FORBES T.D., MUNTIFERING, R.B., BRADLEY, N.W. & FORD, M.J., 1995. Growth and subsequent feedlot performance of estradiol-implanted vs nonimplanted steers grazing fall-accumulated endopyte-infested or low-endophyte tall fescue. *J. Anim. Sci.* 73(6):1576-1584.

BERRY, N.R., SCHEEDER, M.R.L., SUTTER, F., KRÖBER, T.F. & KREUZER, M., 2000. The accuracy of intake estimation based on the use of alkane controlled-release capsules and faeces grab sampling in cows. *Ann. Zootech.* 49(1):3-13.

BOADI, D.A., MOSHTAGHI NIA, S.A., WITTENBERG, K.M. & McCAUGHEY, W.P., 2002. The n-alkane profile of some native and cultivated forages in Canada. *Can. J. Anim. Sci.* 82(3):465-469.

BOLAND, H.T. & SCAGLIA, G., 2011. Case study: Giving beef calves a choice of pasture type influences behavior and performance. *Prof. Anim. Sci.* 27(2):160-166.

BOND, J., POWELL, J.B., UNDERSANDER, D.J., MOE. P.W., TYRELL, H.F. & OLTJEN, R.R., 1984. Forage composition and growth and physiological characteristics of cattle grazing several varieties of tall fescue during summer conditions. *J. Anim. Sci.* 59(3):584-593.

BOSWORTH, S.C., HOVELAND, C.S. & BUCHNAN, G.A., 1985. Forage quality of selected cool-season weed species. *Weed Sci.* 34(1):150-154.

BRADSHAW, A., 1997. Restoration of mined lands - using natural processes. *Ecol. Eng.* 8(4):255-269.

BRADY, N.C. & WEIL, R. R., 1996. *The nature and properties of soils*. 11th ed. Upper Saddle River, N.J.: Prentice-Hall.

BRANSBY, D.I., CONRAD, B.E., DICKS, H.M. & DRANE, J.W., 1988. Justification for grazing intensity experiments: analysing and interpreting grazing data. *J. Range Manage.* 41(4): 274-279.

BRANSBY, D.I., MATCHES, A.G. & KRAUSE, G.F., 1977. Disk meter for rapid estimation of herbage yield in grazing trials*. Agron. J*. 69(3): 393-396.

BRYANT, H.T., BLASER, R.E., HAMMES, R.C. & FONTENOT, J.P., 1970. Symposium on pasture methods for maximum production in beef cattle: effect of grazing management on animal and area output. *J. Anim. Sci.* 30(1): 153-158.

BUCKNER, R.C. & COWAN, J.R., 1973. The fescues. *In: Forages:the science of grassland agriculture.* 3rd ed. Heath, M.E., Metcalfe, D.S., Barnes, R.F. and Hughes, H.De M. (eds)*;* Ames: Iowa State University Press. p. 297-306.

BUGALHO, M.N., DOVE, H., KELMAN, H., WOOD, J.T. & MAYES, R.W., 2004. Plant wax alkanes and alcohols as herbivore diet composition markers. *J. Range Manage*. 57(3):259-268.

BURNS, J.C., 2009. Nutritive value. In: *Tall fescue for the twenty-first century.* Fribourg, H.A., Hannaway, D.B. & West, C.P. (eds.) Madison, Wisc.: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. p. 159-201.

BURNS, J.C. & CHAMBLEE, D.S., 1979. Adaptation. In: *Tall fescue*. Buckner, R.C. & Bush, L.P. (eds.) Madison, Wisc.: American Society of Agronomy. p. 9-30.

BURNS, J.C. & CHAMBLEE, D.S., 2000. Summer accumulation of tall fescue at low elevations in the humid piedmont: II. Fall and winter changes in nutritive value. *Agron. J.* 92(2):217-224.

BURNS, J.C., CHAMBLEE, D.S. & GIESBRECHT, F.G., 2002. Defoliation intensity effects on season-long dry matter distribution and nutritive value of tall fescue. *Crop Sci*. 42(4):1274-1284.

BURNS, J.C. & FISHER, D.S., 2010. Intake and digestibility of improved selections of tall fescue and orchardgrass hays. *Crop Sci*. 50(1):419-426.

BURNS, J.C. & FISHER, D.S., 2011. Stocking strategies as related to animal and pasture productivity of endophyte-free tall fescue. Crop Sci. 51(6):2868-2877.

BURNS, J.C., FISHER, D.S., & POND, K.R., 1991. Tall fescue forage mass and canopy characteristics on steer ingestive behaviour and performance. *Crop Sci*. 51(4):1850-1864.

BURNS, J.C., FISHER, D.S. & ROTTINGHAUS, G.E., 2006. Grazing influences on mass, nutritive value, and persistence of stockpiled Jessup tall fescue without and with novel and wild-type fungal endophytes. *Crop Sci.* 46(5):1898-1912.

BURNS, J.C., POND, K.R. & FISHER, D.S., 1991. Effects of grass species on grazing steers: II. Dry matter intake and digesta kinetics. *J. Anim. Sci*. 69(3):1199-1204.

BUTRIS, G.Y. & PHILLIPS, C.J.C., 1987. The effect of herbage surface water and the provision of supplementary forage on the intake and feeding behaviour of cattle. *Grass Forage Sci.* 42(3):259–264.

BUXTON, D.R., 1996. Quality-related characteristics of forages as influenced by plant environment and agronomic factors. *Anim. Feed Sci. Technol*. 59(1):37-49.

CABRERA ESTRADA, J.I., DELANGARDE, R., FAVERDIN, P. & PEYRAUD, J.L., 2003. The addition of external water to fresh grass does not affect dry matter intake, feeding behaviour and rumen characteristics in dairy cows. *Anim. Res*. 52(1):3-16.

CABRERA ESTRADA, J.I., DELAGARDE, R., FAVERDIN, P. & PEYRAUD, J.L., 2004. Dry matter intake and eating rate of grass by dairy cows is restricted by internal, but not external water. *Anim. Feed Sci. Technol.* 114(1):59-74.

CAIRNS, J., 1983. Management options for rehabilitation and enhancement of surface mined ecosystems. *Miner. Environ.* 5(1):32-38.

CALLOW, M.N., LOWE, K.F., BOWDLER, T.M., LOWE, S.A. & GOBIUS, N.R., 2003. Dry matter yield, forage quality and persistence of tall fescue (*Festuca arundinacea*) cultivars compared with perennial ryegrass (*Lolium perenne*) in a subtropical environment. *Aust. J. Exp. Agr.* 43(9):1093-1099.

CASLER, M.D. & VAN SANTEN, E., 2008. Fungal endophyte removal does not reduce cold tolerance of tall fescue. *Crop Sci.* 48(3):2033-2039.

CHACON, E. & STOBBS, T.H., 1976. Influence of progressive defoliation of a grass sward on eating behaviour of cattle. *Aust. J. Agr. Res.* 27(5):709-727.

CHAVES, A.V., BURKE, J.L., WAGHORN, G.C. & BROOKES, I.M., 2006. Digestion kinetics of leaf, stem and inflorescence from five species of mature grasses. *J. Sci. Food Agric* 86(5):816-825.

CHERNEY, D.J.R., CHERNEY, J.H. & LUCEY, R.F., 1993. *In vitro* digestion kinetics and quality of perennial grasses as influenced by forage maturity. *J. Dairy Sci.* 76(3):790-797.

COLEMAN, S.W. & MOORE, J.E., 2003. Feed quality and animal performance. *Field Crop Res.* 84(1):17-29.

COLLINS, M., 1991. Nitrogen effects on yield and forage quality of perennial ryegrass and tall fescue. *Agron. J*. 83(3):588-595.

COLLINS, M. & BALASKO, J.A., 1981. Effects of N fertilization and cutting schedules on stockpiled tall fescue. II. Forage quality. *Agron. J.* 73(5):821-826.

COLLINS, M. & CASLER, M.D., 1990. Forage quality of five cool-season grasses. I. Cultivar effects. *Anim. Feed Sci. Technol.* 27(3):197-207.

CONRAD, H.R., PATT, A.D. & HIBBS, J.W., 1964. Regulation of feed intake in dairy cows. I. Change in importance of physical and physiological factors with increasing digestibility. *J. Dairy Sci.* 47(1):54-62.

COOPER, J.P. & TAINTON, N.M., 1968. Light and temperature requirements for the growth of tropical and temperate grasses. *Herb. Abstr.* 38(3):167-176.

CORTES, C., DAMASCENO, J.C., BECHET, G. & PRACHE, S., 2005. Species composition of ryegrass (*Lolium perenne*) and tall fescue (*Festuca arundinacea*) mixtures using various combinations of *n*-alkanes. *Grass Forage Sci.* 60(4):254-261.

CRUYWAGEN, C.W., 2006. Technical note: A method to facilitate retrieval of polyester bags used in *in sacco*trials in ruminants. *J. Dairy Sci.* 89(3):1028-1030.

DALLEY, D.E., ROCHE, J.R., GRAINGER, C. & MOATE, P.J., 1999. Dry matter intake, nutrient selection and milk production of dairy cows grazing rainfed perennial pastures at different herbage allowances in spring. *Aust. J. Exp. Agric.* 39(8):923–31.

DECRUYENAERE, V., BULDGEN, A. & STILMANT, D., 2009. Factors affecting intake by grazing ruminants and related quantification methods: a review. *Biotechnol. Agron. Soc. Environ.* 13(4):559-573.

DE OLIVEIRA, D.M., DE QUEIROZ MANELLA, M., TEDESCHI, L.M., DA SILVA, C. & LANNA, D.P.D., 2008. N-alkanes to estimate voluntary forage intake of cattle using controlled-release capsules. *Sci. Agr.* 65(3):230-238.

DERNER, J.D., HART, R.H., SMITH, M.A. & WAFFONER, J.W., 2008. Long-term cattle gain responses to stocking rate and grazing systems in northern mixed-grass prairie. *Livest. Sci.* 117(1):60-69.

DONAGHY, D.J., TURNER, L.R. & ADAMCZEWSKI, K.A., 2008. Effect of defoliation management on water-soluble carbohydrate energy reserves, dry matter yields, and herbage quality of tall fescue. *Agron. J.* 100(1):122-127.

DOVE, H. & MAYES, R.W., 1991. The use of plant wax alkanes as marker substances in studies of the nutrition of herbivores: a review. *Aust. J. Agr. Res*. 42(6):913-952.

DOVE, H. & MAYES, R.W., 2005. Using *n*-alkanes and other plant wax components to estimate intake, digestibility and diet composition of grazing/browsing sheep and goats. *Small Ruminant Res.* 59(2):123-139.

DOVE, H. & MAYES, R.W., 2006. Protocol for the analysis of *n*-alkanes and other plant-wax compounds and for their use as markers for quantifying the nutrient supply of large mammalian herbivores. *Nat. Protoc.* 1(4):1680-1697.

DOVE, H., MAYES, R.W., LAMB, C.S. & ELLIS, K.J., 2002. Factors influencing the release rate of alkanes from an intra-ruminal, controlled-release device, and the resultant accuracy of intake estimation in sheep. *Aust. J. Agr. Res*. 53(6):681-696.

DRAPEAU, R., BÉLANGER, G., TREMBLAY, G.F. & MICHAUD, R., 2007. Yield, persistence, and nutritive value of autumn-harvested tall fescue. *Can. J. Plant sci*. 87(1):67-75.

DREWNOSKI, M.E., OLIPHANT, E.J., MARSHALL, B.T., POORE, M.H., GREEN, J.T. & HOCKETT, M.E., 2009. Performance of growing cattle grazing stockpiled Jesup tall fescue with varying endophyte status. *J. Anim. Sci*. 87(3):1034-1041.

DUGMORE, T.J., WALSH, K.P., MORNING, S.J. & MACDONALD, C.I., 1992. Chemical composition and nutritive value of irrigated tall fescue pasture for dairy cows. *S. Afr. J. Anim. Sci.* 22(3):81-86.

ECK, H.V., WILSON, G.C. & MARTINEZ, T., 1981. Tall fescue and smooth bromegrass. II. Effects of nitrogen fertilization and irrigation regimes on quality. *Agron. J.* 73(3):453-456.

ELIZALDE, J.C., MERCHEN, N.R. & FAULKNER, D.B., 1999a. Fraction of fiber and crude protein in fresh forages during the spring growth. *J. Anim. Sci*. 77(2):476-484.

ELIZALDE, J.C., MERCHEN, N.R. & FAULKNER, D.B., 1999b. *In situ* dry matter and crude protein degradation of fresh forage during spring growth. *J. Dairy Sci.* 82(9):1978-1990.

FAVERDIN, P., 1999. The effect of nutrients on feed intake in ruminants. *P. Nutr. Soc.* 58(3):523-531.

FERREIRA, L.M.M., OLIVÁN, M., RODRIGUES, M.A.M., OSORO, K., DOVE, H. & DIAS-DA-SILVA, A., 2004. Estimation of feed intake by cattle using controlled-release capsules containing n-alkanes or chromium sesquioxide. *J. Anim. Sci.* 142(2):225-234.

FISHER, D.S., BURNS J.C., POND K.R., MOCHRIE R.D. & TIMOTHY D.H., 1991. Effects of grass species on grazing steers: I. Diet composition and ingestive mastication. *J. Anim. Sci.* 69(3):1188-1198.

FLORES, R., COBLENTZ, W.K., OGDEN, R.K., COFFEY, K.P., LOOPER, M.L., WEST, C.P. & ROSENKRANS, C.F., 2007. Effects of fescue type and sampling date on the ruminal disappearance kinetics of autumn-stockpiled tall fescue. *J. Dairy Sci.* 90(6):2883-2896.

FORBES, J.M., 1996. Integration of regulatory signals controlling forage intake in ruminants. *J. Anim. Sci.* 74(12):3029-3035.

GIBSON, D.J. & NEWMAN, J.A., 2001. *Festuca arundinacea* Schreber (*F. elatior* L. ssp. *arundinacea* (Schreber) Hackel). *J. Ecol.* 89(2):304-324.

GIRON, H.C., 1973. Atomic absorption *Newsletter* 12, 28. Perkin Elmer Atomic Spectrophotometer.

GRUNOW, J.O. & RABIE, J.W., 1985. Production and quality norms of certain grass species for fodder flow planning: Pretoria area. *J. Grassl. Soc. South Afr*. 2 (2):23-28.

HEDTCKE, J.L., UNDERSANDER, D.J., CASLER, M.D. & COMBS, D.K., 2002. Quality of forage stockpiled in Wisconsin. *J. Range Manage.* 55(1):33-42.

HOPKINS, A.A. & ALISON M.W., 2006. Stand persistence and animal performance for tall fescue endophyte combinations in the south central USA. *Agron. J.* 98(5):1221-1226.

HOWARD, M.D.,MUNTIFERING, R.B., BRADLEY, N.W., MITCHELL, G.E.& LOWRY, S.R., 1992. Voluntary intake and ingestive behaviour of steers grazing Johnstone or endophyte-infected Kentucky-31 tall fescue. *J.Anim. Sci*. 70(4):1227-1237.

HUNTER, R.A. & SIEBERT, B.D., 1986. The effects of genotype, age, pregnancy, lactation and rumen characteristics on voluntary intake of roughage diets by cattle. *Aust. J. Agr. Res.* 37(5):549-560.

INTERRENATE, S.M., BIERMACHER, J.T., KERING, M.K.& BUTLER, T.J., 2012. Production and economics of steers grazing tall fescue with annual legumes or fertilized with nitrogen. *Crop Sci.* 52(4):1940-1948.

JOHNSON, J.M., AIKEN, G.E., PHILLIPS, T.D., BARRETT, M., KLOTZ, J.L. & SCHRICK, F.N., 2012. Steer and pasture responses for a novel endophyte tall fescue developed for the upper transition zone. *J. Anim. Sci*. 90(7):2402-2409.

JOVANOVIC, N.Z., BARNARD, R.O., RETHMAN, N.F.G. & ANNANDALE, J.G., 1998. Crops can be irrigated with lime treated acid mine drainage. *Water SA* 24(2):113-122.

JOVANOVIC, N.Z., ANNANDALE, J.G., CLAASSENS, A.S., LORENTZ, S.A., TANNER, P.D., AKEN, M.E. & HODGSON, F.D.I., 2002. Commercial production of crops irrigated with gypsiferous mine water. *Water SA* 28(4):413-422.

JUNG, H.G. & ALLEN, M.S., 1995. Characteristics of plant cell walls affecting intake and digestibility of forages by ruminants. *J. Anim. Sci.* 73(9):2774-2790.

JUNG, H.G. & SAHLU, H., 1989. Influence of grazing pressure on forage quality and intake of sheep grazing smooth bromegrass. *J. Anim. Sci.* 67(8):2089-2097.

KABILIGI, J.F., MOSS, B.R., DAVENPORT, G.M., HOLLIMAN, J.L., BRANSBY, D.I. & LIN, J.C., 1995. Composition, digestibility and utilization of endophyte-free tall fescue fed as green-chop or hay to sheep. *Small Ruminant Res.* 17(3):199-205.

KENNEY, P.A., BLACK, J.L. & COLEBROOK, W.F., 1984. Factors affecting diet selection by sheep. III. Dry matter concentration and particle length of forage. *Aust. J. Agr. Res.* 35(6):831-838.

KLUG, J.R., VAN HEERDEN, J.M. & LISHAMAN, A.W., 2000. Fodder production planning and livestock production systems. In: *Pasture management in South Africa*. Tainton, N.M. (ed.) Pietermaritzburg: University of Natal Press. p. 296-320.

KOBAYASHI, H., SATO, S. & MASAOKA, Y., 2004. Tolerance of grasses to calcium chloride, magnesium chloride and sodium chloride. *Plant Prod. Sci.* 7(1):30-35.

LACEFIELD, G.D., HENNING, J.C. & PHILLIPS, T.D., 2003. *Tall fescue*. University of Kentucky, College of Agriculture. Cooperative Extension Service. Publication AGR-59.

LANGLANDS, J.P. & SANSON, J., 1976. Factors affecting nutritive value of the diet and the composition of rumen fluid of grazing sheep and cattle. Aust. *J. Agric. Res*. 27(5):691-707.

LIMPITLAW, D., AKEN, M., LODEWIJKS, H. & VILJOEN, J., 2005. Post-mining rehabilitation, land use and pollution at collieries in South Africa. South African Institute of Mining and Metallurgy. *Sustainable development in the life of coal mining.* Colloquium presented atBoksburg, 13 July. Unpublished.

LIPIEC, J. & STĘPNIEWSKI, W., 1995. Effects of soil compaction and tillage systems on uptake and losses of nutrients. *Soil Tillage Res.* 35(1-2):37-52.

MacADAM, J.W., DROST, D.T., DUDLEY, L.M. & SOLTANI, N., 1997. Shoot growth, plant tissue elemental composition, and soil salinity following irrigation of alfalfa and tall fescue with high-sulfate waters. *J. Plant Nutr.* 20(9):1137-1153.

MARKS, S. & CLAY, K., 1996. Physiological responses of *Festuca arundinacea* to fungal endophyte infection. *New Phytol.* 133(4):727-733.

McCRACKEN, B.A., KRYSL, L.J., PARK, K.K., HOLCOMBE, D.W. & JUDKINS, M.B., 1993. Steers grazing endophyte-free tall fescue: seasonal changes in nutrient quality, forage intake, digesta kinetics, ruminal fermentation, and serum hormones and metabolites. *J. Anim. Sci.* 71(6):1588-1595.

McDONALD, P., EDWARDS, R.A., GREENHALGH, J.F.D. & MORGAN, C.A., 2001. *Animal Nutrition.* 6th ed. Harlow, England: Prentice Hall.

MERCURI, A.M., DUGGIN, J.A. & GRANT, C.D., 2005. The use of saline mine water and municipal wastes to establish plantations on rehabilitated open-cut coal mines, Upper Hunter Valley NSW, Australia. *Forest Ecol. Manag.* 204(2-3):195-207.

MINSON, D.J., 1990. *Forage in ruminant nutrition*. San Diego: Academic Press.

MOORE, J.E., BRANT, H., KUNKLE, W.E. & HOPKINS, D.I., 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. *J. Anim. Sci.* 77, Suppl. 2:122-135.

MOSEBI, P.E., 2010. *The role of living plant roots and cattle manure as a soil amendment in the alleviation of compacted coal mines*. M.Sc.(Agric) dissertation. Pretoria: University of Pretoria.

MURRAY, R.B., 1984. Yields, nutrient quality, and palatability to sheep of fourteen grass accessions for potential use on sagebrush-grass range in Southeastern Idaho. *J. Range Manage.* 37(4):343-348.

NIHSEN, M.E., PIPER, E.L., WEST, C.P., CRAWFORD, R.J., DENARD, T.M., JOHNSON, Z.B., ROBERTS, C.A., SPIERS, D.A. & ROSENKRANS, C.F., 2004.Growht rate and physiology of steers grazing tall fescue inoculated with novel endophytes. *J. Anim. Sci*. 82(3):878-883.

NORDHEIM-VIKEN, H., VOLDEN, H. & JØRGENSEN, M., 2009. Effects of maturity stage, temperature and photoperiod on growth and nutritive value of timoty (*Phleum pratense* L.). *Anim. Feed Sci. Technol.* 152(3-4):204-218.

NRC, 1996. Nutrient requirements of beefcattle. 7th ed. Natl. Acad. Press, Washington,D.C.

ØRSKOV, E.R. & McDONALD, I., 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. *J. Agr. Sci. (Camb.)* 92(2):499-503.

ØRSKOV, E.R., HOVELL, F.D. & MOULD, F., 1980. The use of nylon bag technique for the evaluation of feedstuffs. *Trop. Anim. Prod.* 5(3):195-213.

OLIVÁN, M., FERREIRA, L.M.M., CELAYA, R. & OSORO, K., 2007. Accuracy of the n-alkane technique for intake estimation in beef cattle using different sampling procedures and feeding levels. *Livest. Sci.* 106(1):28-40.

PARISH, J.A., McCANN, M. A., WATSON, R.H., HOVELAND, C.S., HAWKINS, L.L., HILL, N.S. & BOUTON, J. H., 2003a. Use of nonergot alkaloid-producing endophytes for alleviating tall fescue toxicosis in sheep. *J. Anim. Sci.* 81(5):1316-1322.

PARISH, J.A., McCANN, M.A., WATSON, R.H., PAIVA, N.N., HOVELAND, C.S., PARKS, A.H., UPCHURCH, B.L., HILL, N.S. & BOUTON, J.H., 2003b. Use of nonergot alkaloid-producing endophytes for alleviating tall fescue toxicosis in stocker cattle. *J. Anim. Sci*. 81(11):2856-2868.

PEDERSEN, J.F., LACEFIELD, G.D. & BALL, D.M., 1990. A review of the agronomic characteristics of endophyte-free and endophyte-infected tall fescue. *Appl. Agric. Res.* 5(3):188-194.

PENDLUM, L.C., BOLING., J.A., BUSH, L.P. & BUCKNER, R.C., 1980. Digestibility and metabolism of Kenhy tall fescue harvested at three stages of physiological maturity. *J. Anim. Sci*. 51(3):704-711.

PETERS, C.W., GRIGSBY, K.N., ALDRICH, C.G., PATERSON, J.A., LIPSEY, R.J., KERLEY, M.S. & GARNER, G.B., 1992. Performance, forage utilization, and ergovaline consumption by beef cows grazing endophyte fungus-infected tall fescue, endophyte fungus-free tall fescue, or orchard grass pastures. *J. Anim. Sci*. 70(5):1550-1561.

PEYRAUD, J.L. & ASTIGARRAGA, L., 1998. Review of the effect of nitrogen fertilization on the chemical composition, intake, digestion and nutritive value of fresh herbage: consequences on animal nutrition and N balance. *Anim. Feed Sci. Technol.* 72(3-4):235-259.

PHILLIPS, C.J.C., MARGERISON, J.K., AZAZI, S., CHAMBERLAIN, A.G. & OMED, H., 1991. The effect of adding surface water to herbage on its digestion by ruminants. *Grass Forage Sci.* 46(3):333–338.

PIASENTIER, E., BOVOLENTA, S., MALOSSINI, F. & SUSMEL, P., 1995. Comparison of *n*-alkanes or chromium oxide methods for estimation of herbage intake by sheep. *Small Ruminant Res.* 18(1):27-32.

POORE, M.H., SCHOTT, M.E. & GREEN J.T., 2006. Performance of beef heifers grazing stockpiled fescue as influenced by supplemental whole cottonseed. *J. Anim. Sci*. 84(6):1613-1625.

POWELL, K., REID R.L. & BALASKO J.A., 1978. Performance of lambs on perennial ryegrass, smooth bromegrass, orchardgrass and tall fescue pastures II. Mineral utilization, *in vitro* digestibility and chemical composition of herbage. *J. Anim. Sci*. 46(6):1503-1514.

RAESIDAE, M.C., FRIEND, M.A., BEHRENDT, R., LAWSON, A.R. & CLARK, S.G., 2012. Evaluation of tall fescue (*Festuca arundinacea*) as a forage for sheep in the temperate high-rainfall zone of south-eastern Australia.*Grass Forage Sci.* 67(3):411-425.

REID, R.L., JUNG, G.A. & THAYNE, W.V., 1988. Relationships between nutritive quality and fiber conponents of cool season and warm season forages: A retrospective study. *J. Anim. Sci.* 66(5):1275-1291.

REID, R.L., POWELL, K., BALASKO, J.A. & McCORNICK, C.C., 1978. Performance of lambs on perennial ryegrass, smooth bromegrass, orchardgrass, and tall fescue pasture I. Live weight changes, digestiblity and intake of herbage. *J. Anim. Sci*. 46(6):1493-1502.

RHIND, S.M., ARCHER, Z.A. & ADAM C.L., 2002. Seasonality of food intake in ruminants: recent developments in understanding. *Nutr. Res. Rev*. 15(1):43-66.

ROBERTSON J.B. & VAN SOEST, P.J., 1981. The analysis of dietary fiber in food. James, W.P.T. &Theander, O. (Eds). Dekker, New York. ADSRI - JAN 1998.

ROBSON, M.J., 1972. The effect of temperature on the growth of S.170 tall fescue (*Festuca aurundinacea*). I. Constant temperature. *J. Appl. Ecol.* 9(2):643-653.

ROMNEY, D.L. & GILL, M., 2000. Intake of forages. In: *Forage evaluation in ruminant nutrition*. Givens, D.I., Owen, E., Axford, R.F.E. & Omed, H.M. (eds.) Wallingford, Oxon.: CABI Publishing. p. 43-62.

SAKAI, A. & LARCHER, W., 1987. *Frost survival of plants: responses and adaptations to freezing stress.* Berlin: Springer.

SALISBURY, F.B. & ROSS, C.W., 1992. *Plant physiology*. 4th ed. Belmont, Calif.: Wadsworth.

SAMUELS, M.L., 1989. *Statistics for the life sciences*. San Francisco: Dellen.

SANDBERG, R.E, ADAMS, D.C., KLOPFENSTEIN, T.J. & GRANT, R.J., 2000. N-alkane as an internal marker for predicting digestibility of forages. *J. Range Manage.* 53(2):159-163.

SCHMIDT, S.P. & OSBORN, T.G., 1993. Effects of endophyte-infected tall fescue on animal performance. *Agr. Ecosyst. Environ.* 44(1-4):233-262.

SINCLAIR, K., FULKERSON, W.J. & MORRIS, S.G., 2006. Influence of regrowth time om the forage quality of prairie grass, perennial ryegrass and tall fescue under non-limiting soil nutrient and moisture conditions. *Aust. J. Exp. Agric.* 46:45-51.

SOLLENBERGER, L.E. & VANZANT, E.S., 2011. Interrelationships among forage nutritive value and quantitative and individual animal performance. *Crop Sci.* 51(2):420-432.

STATISTICAL ANALYSIS SYSTEMS, 2009. SAS User's Guide : Statistics Version 9.2 SAS Institute Inc. Cary, NC, USA.

STEWART, R.L., SCAGLIA, G., ABAYE, O.A., SWECKER, W.S., ROTTINGHAUS, G.E., BOLAND, H.T., McCANN, M. & FONTENOT, J.P., 2008. Estimation of forage intake by steers gazing three fescue types and determination of alkaloids in ruminal fluid and forage. *Prof. Anim. Sci.* 24(6): 578-587.

THE ROYAL SOCIETY, 2009. *Reaping the benefits: science and the sustainable intensification of global agriculture*. London: The Royal Society. RS policy document 11/09. RS1608.

THOMPSON, F.N. & STUEDEMANN, J.A., 1993. Pathophysiology of fescue toxicosis. *Agr. Ecosyst. Environ.* 44(1-4):263-281.

TILLEY, J.M.A. & TERRY, R.A., 1963. A two-stage technique for the *in vitro* digestion of forage crops. *Grass Forage Sci.* 18(2):104-111.

ULYATT, M.J., 1973. The feeding value of herbage. In: *Chemistry and biochemistry of herbage*. Butler, G.W & Bailey, R.W. (eds.) London: Academic Press. p. 131-378.

VANZANT, E.S., COCHRAN, R.C. & JOHNSON, D.E., 1991. Pregnancy and lactation in beef heifers grazing tallgrass prairie in the winter: influence on intake, forage utilization, and grazing behavior. *J. Anim. Sci.* 69(7):3027-3038.

VAVRA, M., RICE, R.W. & BEMENT, R.E., 1973. Chemical composition of the diet, intake and gain of yearling cattle on different grazing intensities. *J. Anim. Sci.* 36(2):411-414.

VECELLIO, L.C., JUNG, G.A., HARPSTER, H.W., SHAFFER, J.A., ENGLE, C.E. & EVERHART, J.R., 1995. Endophyte-free tall fescue cultivars grazed by sheep: forage quality and sward characteristics. *Agron. J*. 87(6):1169-1175.

VERMAAK, H.J., 2011. *Effect of dietary energy and fiber source on rumen function in feedlot steers.* M.Sc.(Agric)-thesis. Pretoria: University of Pretoria. Unpublished.

VOLESKY, J.D., ANDERSON, B.E. & STOCTON, M.C., 2008. Species and stockpile initiation date effects on yield and nutritive value of irrigated cool-season grasses. *Agron. J.* 100(4):931-937.

WESTON, R.H., 1982. Animal factors affecting feed intake. In: *Nutritional limits to animal production from pastures*. Hacker, J.B. (ed.) Farnham Royal, Slough: CAB. p. 183-198.

WHEELER, J.L., BURNS, J.C., MOCHRIE, R.D. & GROSS, H.D., 1973. The choice of fixed or variable stocking rates in grazing experiments. *Exp. Agr.* 9(4):289-302.

WILKINSON, S.R. & MAYS, D.A., 1979. Mineral Nutrition. In: *Tall fescue*. Buckner, R.C. & Bush, L.P. (eds.) Madison, Wisc.: American Society of Agronomy. p. 41-73.

WOLF, D. & OPITZ VON BOBERFELD, W., 2003. Effects of nitrogen fertilization and date of utilization on the quality and yield of tall fescue in winter. *J. Agron. Crop Sci.* 189(1):47-53.

ZHANG, Y., TOGAMURA, Y. & OTSUKI, K., 2004. Study on the *n*-alkane patterns in some grasses and factors affecting the *n*-alkane patterns. *J. Anim. Sci.* 142(4): 469-475.