Understanding Sheep Grazing in Native Pastures to Better Manage Animal and Pasture Production

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Certificate of Authorship

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17th June 2013
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Abstract
Sheep production on grasslands depends upon the quantity and quality of forage consumed. However, limited information exists on what sheep grazing within complex native pastures within the high rainfall zone of south-eastern Australia eat and the quality of their diet. Grazing practices used also affect the sustainability of grasslands. Producers commonly implement various forms of grazing management ranging from set-stocking or continuous grazing through to intensive forms of rotational grazing, but limited objective information exists as to the effect of grazing systems on the quality of the diet and grazing behaviour as well as the management of animals within these systems. A study was undertaken to investigate these factors in a series of experiments at the Central Tablelands EverGraze Proof Site at Panuara (33°27'S, 148°33'E) in New South Wales, from October 2009 to December 2011. The EverGraze experiment was established within a heterogeneous landscape and native pasture in 2008 and was designed to evaluate three grazing systems viz. low-intensity; 1-paddock continuous grazing (CG) treatment, medium-intensity; 4-paddock flexible rotational grazing treatment, high-intensity; and 20-paddock flexible rotational grazing (RG) treatment in a randomised-block design. The CG and RG treatments were used for this study. Each treatment plot was 3.5 ha in size and there were three replicate blocks.

In addition to the main experimental plots, four small additional replicate plots were established at the site outside of the main grazing experiment, maintained as per treatment protocols, and were periodically grazed by 20 dry ewes. These allowed the detailed examination of the animals’ diet selection over time via intensive pasture monitoring and faecal analysis as well as the testing and refinement of methods. Throughout this study the live weight, body condition scores (BCS) and wool production of the ewes as well as the live weight of their lambs was measured. Wool production parameters included staple length, strength, fibre diameter, position of break (POB) and the minimum and maximum fibre diameter along the staple of mid-side samples.

Two detailed studies of the composition and quality of the diet of ewes managed within the contrasting grazing systems (1-paddock CG and 20-paddock RG) were completed, one in spring when ewes were lactating and one in autumn when they were dry and not pregnant. During each replicate study the location, activity and landscape use of the animals was monitored using global positioning system (GPS) collars.
During both small plot studies and the larger grazing experiment, faecal samples and plant material were collected and analysed for proximate composition. The quality of the diet of the sheep was estimated using faecal chemistry equations, two for organic matter digestibility (OMD_M and OMD_w) and one for metabolisable energy (ME_M).

An animal house feeding experiment was undertaken in Wagga Wagga (35°2’S, 147°19’E), NSW, after the field work to examine the digestibility of four diets of native pasture harvested (and dried) at the EverGraze site (at four separate time periods) (n = 24). A faecal model was developed to predict diet quality and evaluate the OMD_M, OMD_w and ME_M predictive equations. In addition, the usefulness of faecal near infrared reflectance spectroscopy (fNIRS) to estimate diet quality parameters was investigated.

Ewe live weight, BCS and lamb live weight per head within the CG system consistently out performed (p < 0.05) RG ewes (and their lambs). However, there were no differences (p > 0.05) between production systems in wool quality and production.

Grazing sheep consistently selected the green vegetative plant material from within a pasture and the species selected varied seasonally. The mechanisms underlying this selection were related to the initial green to dead ratio of dry matter (DM) for a plant species and the spatial arrangement of plant components within a pasture; sheep were more likely to consume a greater proportion of a species when the initial green to dead ratio was 3 or more.

Wool production was affected by differences in climatic conditions between years. Overall wool production and quality was greater in wool harvested in 2010 than 2011. Greater variability in fibre diameter was recorded in 2010 wool samples that coincided with highly variable rainfall and temperature conditions (the highest and lowest rainfall and temperature conditions of the study period). Similarly, the live weight and BCS of ewes from both treatments was affected by differences in climatic condition between years. The highest live weight and BCS were recorded in 2010, which had the highest annual rainfall and greater quantities of quality vegetative green feed.

The measured (based on results from the animal house study) digestibility and metabolisable energy (ME) of the native pasture at the site was lower than values from in vitro analysis of hand-plucked pasture samples, predicted faecal equations and the GrazFeed® decision support tool. In this case the differences were likely to be a result of the method of harvesting large quantities of pasture and the pre-feeding treatment of
drying and storing the pasture. Due to low levels of herbage mass harvesting sufficient material for feeding studies took a long time, which meant samples probably respired significant amounts of the more volatile material before they could be dried. However, relative comparisons could still be made. An accurate predictive model of diet quality from faecal chemical indices was unable to be derived from the dataset as a result of the limited dataset, narrow range of forage nutritive value and small number of diets in the study. Equations to predict diet quality (DM digestibility (DMD), organic matter digestibility (OMD) and perhaps metabolisable energy (ME)) were successfully developed from NIRS that allowed qualitative comparisons of diet quality; however, further development of an accurate, quantitative, non-invasive method of predicting the diet quality of grazing animals is essential.

The greater production of animals grazing within a CG system is likely to be a consequence of the animals’ maintaining areas (patches) of high quality pasture and potentially consuming greater quantities of DM and ME. The intake of RG ewes was estimated from pasture biomass assessments and when compared to values predicted by the decision support tool GrazFeed® the values were alike and provided a reliable means of the estimation of DM and ME intake of RG and CG animals.

The diet quality values derived from predictive equations were not correlated with the actual values/parameters of the diet consumed by sheep. However, the predictive equation of OMD, recorded similar trends in diet quality and thus provided a means of qualitative comparisons of diet quality between animals and grazing treatments.

Overall the diet selection of sheep grazing within heterogeneous native pastures appears to be primarily related to the spatial arrangement of plant components within a pasture and the initial green to dead ratio of DM of forage and also influenced by the digestible organic matter within the dry matter (DOMD) of each pasture species. Unless RG systems take grazing behaviour and diet selection into account they can depress sheep live weight and BCS as a result of restricting the animal’s ability to select forage and optimise landscape utilisation.

The use of relatively simple, low cost and non-invasive methods has expanded the knowledge of sheep nutrition within the region. This additional knowledge can assist livestock producers within the region to make more objective decisions of the management of livestock within grazing systems and native pastures.
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## Glossary of Terms

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<th>Term</th>
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<td>AAs</td>
<td>Amino acids</td>
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<td>ADF</td>
<td>Acid detergent fibre</td>
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<td>ADL</td>
<td>Acid detergent lignin</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
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<tr>
<td>ATLAS</td>
<td>Automatic tester of length and strength</td>
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<td>BCS</td>
<td>Body condition score</td>
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<td>C</td>
<td>Carbon</td>
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<td>CFW</td>
<td>Clean fleece weight(s)</td>
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<td>CG</td>
<td>Continuous grazing</td>
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<td>CP</td>
<td>Crude protein</td>
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<td>CPD</td>
<td>Crude protein digestibility</td>
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<td>CPI</td>
<td>Crude protein intake</td>
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<td>CVFD</td>
<td>Coefficient of variation of fibre diameter</td>
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<td>DE</td>
<td>Digestible energy</td>
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<td>DM</td>
<td>Dry matter</td>
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<td>DMD</td>
<td>Dry matter digestibility</td>
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<td>DOMD</td>
<td>Digestible organic matter within the dry matter</td>
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<td>DSE</td>
<td>Dry sheep equivalent (where 1 DSE was equivalent to a 50 kg dry, not pregnant ewe in condition score 3.0)</td>
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<td>fADL</td>
<td>Faecal acid detergent lignin</td>
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<td>fAsh</td>
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<td>fCP</td>
<td>Faecal crude protein</td>
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<td>fN</td>
<td>Faecal nitrogen</td>
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<td>fNDF</td>
<td>Faecal neutral detergent fibre</td>
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<td>Abbreviation</td>
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<td>FOO</td>
<td>Food on offer</td>
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<td>GFW</td>
<td>Greasy fleece weight(s)</td>
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<td>GIS</td>
<td>Global information system(s)</td>
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<td>GPS</td>
<td>Global positioning system(s)</td>
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<td>HPZ</td>
<td>High production zone</td>
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<td>HRZ</td>
<td>High rainfall zone</td>
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<td>HU</td>
<td>High utilisation</td>
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<td>LPZ</td>
<td>Low production zone</td>
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<td>LU</td>
<td>Low utilisation</td>
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<td>LSD</td>
<td>Least significant difference</td>
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<td>ME</td>
<td>Metabolisable energy</td>
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<tr>
<td>ME&lt;sub&gt;M&lt;/sub&gt;</td>
<td>ME value derived from Mahipala &lt;i&gt;et al.&lt;/i&gt; (2009) equation</td>
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<tr>
<td>MPZ</td>
<td>Medium production zone</td>
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<td>N</td>
<td>Nitrogen</td>
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<td>NDF</td>
<td>Neutral detergent fibre</td>
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<td>NDVI</td>
<td>Normalised difference vegetation index</td>
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<td>NIR</td>
<td>Near infrared reflectance</td>
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<td>NIRS</td>
<td>Near infrared reflectance spectroscopy</td>
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<td>NSC</td>
<td>Non-structural carbohydrates</td>
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<td>NSW</td>
<td>New South Wales</td>
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<td>OM</td>
<td>Organic matter</td>
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<td>OMD</td>
<td>Organic matter digestibility</td>
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<td>OMD&lt;sub&gt;M&lt;/sub&gt;</td>
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<td>OMD\textsubscript{w}</td>
<td>OMD value derived from Wang et al. (2009) equation</td>
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<td>P</td>
<td>Phosphorus</td>
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<td>PCA</td>
<td>Principal component analysis</td>
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<td>POB</td>
<td>Position of break</td>
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<td>R</td>
<td>Reproductive</td>
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<td>REML</td>
<td>Residual maximum likelihood</td>
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<td>RG</td>
<td>Rotational grazing</td>
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<tr>
<td>RPD ratio</td>
<td>Standard error of reference database: standard error of cross validation</td>
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<td>S</td>
<td>Sulphur</td>
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<tr>
<td>Sc</td>
<td>Senescent</td>
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<td>SE</td>
<td>Standard error</td>
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<td>SEC</td>
<td>Standard error of calibration</td>
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<td>SECV</td>
<td>Standard error of cross validation</td>
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<td>SEL</td>
<td>Standard error of laboratory method</td>
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<tr>
<td>SR</td>
<td>Stocking rate(s)</td>
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<td>VFA</td>
<td>Volatile fatty acid(s)</td>
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Chapter 1. Introduction

1.1 Native pastures
Australian native pastures and grasslands have changed considerably since European settlement (Moore 1970; Garden et al. 1996) as a result of the combined effects of grazing by domestic livestock, the introduction of exotic species and the application of fertiliser. Present day native pastures and grasslands are a complex mosaic that may include native and introduced perennial and annual grasses, legumes and forbs (Whalley and Lodge, 1987).

The high rainfall zone (HRZ) of south-eastern Australia is a major livestock and wool production area with highly variable landscapes, climate and pastures that include native, naturalised and improved pastures. Native pastures dominate the grazing lands within New South Wales (NSW) (Garden et al. 2000) and the resulting heterogeneous pastures together with the diverse landscapes and variable climate create a challenging environment for livestock production and research. Livestock producers face the challenging task of maintaining and enhancing the pasture and natural resources to ensure sustainable animal production within these environments. Management decisions are difficult with respect to the implementation of grazing systems and optimising animal performance as a result of the variable environment, together with the lack of reliable information on the nutritive value of the diet consumed by grazing livestock. In the same way, determining the composition and quality of the diet of grazing animals is inherently difficult due to the complex vegetation.

1.2 Livestock production within the HRZ of south-eastern Australia
The HRZ of temperate south-eastern Australia is defined as areas of NSW, Victoria, Tasmania and South Australia with an average annual rainfall of greater than 600 mm (Saul and Chapman 2002) (Figure 1.1). The region includes the tablelands and slopes of NSW, Victoria and Tasmania that are major sheep and wool production areas (Commonwealth of Australia 2007). Within the HRZ native and naturalised pasture species are a dominant component of grazing land within the highly variable landscapes and less productive areas of the region.

Summer temperatures are mild to warm with maximum daily temperatures exceeding 20°C and 30°C for 6-8 months and 2-3 months of the year, respectively.
In summer evaporation exceeds rainfall and pasture growth is limited by soil moisture availability. Winter temperatures are cool and frosts occur over 5-7 months of the year. During winter pasture growth within southern Victoria and South Australia is limited by waterlogging, whereas within the Central Tablelands and Slopes of NSW pasture growth is typically limited more by temperature as rainfall exceeds evaporation (CMA 2008). As a result of the variable landscape and climate the tableland regions of NSW, characterised by variable landscapes and heterogeneous native pastures, have been referred to as rangelands (Price et al. 2005). Similar to other rangelands, the landscape variability within the region results in highly variable pasture composition, growth patterns and primary productivity (Kemp et al. 1996; Johnston 1999; King et al. 2006).

1.3 Management of sheep grazing within native pastures

Significant changes in the botanical composition of pastures within the HRZ of south-eastern Australia have occurred as animal production and grassland management
systems have evolved (Hill et al. 2004). Following European settlement extensive tree clearing occurred in the mid-19th century to allow the development of sheep grazing (Moore 1970). Historically, native grasses were considered to be of low production potential and unable to utilise improved regimens of moisture or nutrients in comparison to introduced species (Donald 1970). As a consequence native grasslands were ‘improved’ by the over-sowing of an introduced pasture such as the legume species *Trifolium subterraneum* together with the widespread application of superphosphate fertiliser. Animals were typically set-stocked within large areas of these pastures and pasture ‘improvement’ allowed a dramatic increase in stocking rates (SR) within the region.

However, within the Central Tablelands and Slopes of NSW drought and increased economic pressures resulted in a dramatic decline in fertiliser and seed inputs that together with overgrazing led to pasture and landscape degradation. Pasture degradation included a reduction in perennial pasture species that resulted in increased variability of forage supply, with feed shortages typically occurring in late summer and early autumn (Kemp and Dowling 1991). The loss of native perennial pasture species was associated with environmental degradation including soil degradation, acidification, salinisation and erosion, all of which ultimately led to a decline in animal productivity (Archer et al. 1993; Kemp et al. 2000; Mason and Kay 2000; Dorrough et al. 2004b). Stocking rates within the region have declined as a result of poor seasonal conditions through the 2000s, summer active native grasses have reinvaded pastures and pasture quality has declined, particularly in winter (Kemp and Michalk 2007).

Understanding of the ecological and economic importance of perennial native grasses has improved since the 19th century and these pastures are now considered to be vital in maintaining biodiversity and healthy landscapes and ecosystems (Johnston 1999; Garden et al. 2000; Kemp and Dowling 2000; Dorrough et al. 2008). However, within the marginal areas of the HRZ (Central Tablelands and Slopes of NSW) declining terms of agricultural trade has resulted in a shift towards low-cost, sustainable management practices. These practices aim to maintain and/or improve pasture composition and landscape health as well as maintain the productivity of grazing sheep (Kemp et al. 2000). The strategic resting of pastures (the removal of grazing) has been found to alter pasture composition and allow the maintenance and/or enhancement of pasture perenniality (as reviewed by Jones and Dowling 2005; Nie and Zollinger, 2011). These
findings have led to the development and implementation of various grazing strategies and systems. These strategies include altering the species of animal, SR, stocking density, herbage allowance, as well as the frequency, timing and duration of grazing and rest (Scarnecchia and Kothmann 1982; Kemp et al. 1996; Dowling et al. 2006). The effect of management strategies and systems on animal production within these landscapes is not clearly understood and the impact on pasture composition appears to be dependent on local conditions (Kemp et al. 2000). Additionally, the lack of objective information to optimally manage grazing systems together with a lack of understanding of the diet selection and nutritive intake of livestock within the region makes management decisions and production difficult.

1.4 Research in sheep grazing native pastures
Grazing ecosystems are extremely complex, interconnected, dynamic, continuously evolving and in the case of heterogeneous landscapes and pastures, poorly understood. Numerous studies (see Chapter 2, section 2.6.2) have been conducted on the effects of grazing systems on the botanical composition and production of native pastures as well as animal production. Very few studies have investigated the grazing selectivity of livestock within native pastures and are limited to small plot grazing studies (Leigh and Holgate 1978). The majority of research has occurred within very controlled experiments that do not adequately represent the highly variable landscapes or the management practices of producers and managers within the region. Consequently the extrapolation of results from these rigid controlled studies to commercial operations are limited (Norton 1998). Furthermore, a large knowledge gap exists in understanding livestock selectivity and nutrition of animals grazing within native pastures. A major factor limiting this understanding is the availability of applicable methods to assess animal selectivity within heterogeneous landscapes and pastures. The application of traditional methods to monitor selection and diet composition of grazing animals such as observation studies, oesophageal- and rumen-fistulation are of limited use in diverse native pastures (see Chapter 2, sections 2.3 and 2.4). Research on grazing animals within heterogeneous native pastures needs to be flexible for results to be applicable to commercial operations (Laca 2009).

1.5 Study background and significance
Native pastures within the HRZ of south-eastern Australia are important for livestock production within the region and in terms of biodiversity, healthy landscapes and
ecosystems. Producers and managers face the challenge of optimising animal production whilst maintaining and enhancing economic viability and the sustainability of pastures and natural resources. This has resulted in producers and managers pursuing or implementing some form of rotational grazing (RG) management strategies. However, very little objective information is available to assist producers in optimising decisions of when and why to move animals between paddocks. Decisions to move livestock based on the stage of leaf growth (Fulkerson and Slack 1994; Fulkerson and Donaghy 2001) or biomass (Curtis and O’Brien 1994) of perennial ryegrass that are applied within the dairy industry cannot simply be applied to native pastures. Leaf stage parameters to determine the commencement of grazing have been developed for native grasses (Department of Primary Industries, 2011). However, their application is limited within the diverse environments and landscapes and complex pastures of the study region due to the presence of multiple desirable species that vary in development and the influence of variable topography on microclimate that further enhances differences. Thus a greater understanding of the grazing process in terms of diet selection (plant species, stage of growth and plant parts), diet quality, foraging behaviour and landscape use of animals grazing within native pastures and grazing systems is essential to the development and refinement of management practices within these complex environments and pastures. Research within these diverse landscapes and pastures is complicated by the need for large sample sizes to account for the high variability within these landscapes and limited time and available money.

An established study within the region (the EverGraze Central Tablelands Proof Site at Panuara (33°27’S, 148°33’E) in the central west of NSW) has been used by other researchers to investigate how grazing systems and topography affect the productivity of grasslands, livestock and natural resources of native pastures. The research undertaken has been to compare set-stocking and flexible high-intensity short-duration grazing systems that were designed to reflect management practices used by producers within the region (via a producer-based steering committee). The focus of the research has been to investigate the basic mechanisms underlying the success or failure of grazing practices and systems.

The original aim of the research reported in this thesis was to build on and contribute to the work of the established study and compare the diet quality and selection of animals grazing within RG and continuous grazing (CG) systems within native pastures. Due to
limited application of non-invasive techniques within these complex environments the aim of the research was expanded to develop and test non-invasive methodologies of determining the diet selection, diet quality and grazing location and behaviour of sheep grazing within native pastures and contrasting grazing systems.

Knowledge of sheep nutrition and diet selection within native pastures is severely limited, which makes management decisions about grazing systems and livestock difficult. The overall aim of the research reported in this thesis was to gain a greater understanding of the nutrition of sheep grazing within native pastures and to develop and investigate low-cost, non-invasive methods of determining sheep nutrition. The project objectives were to build knowledge and tools to better advise producers and researchers of the nutritive value of native pastures, to identify what animals are actually consuming and their activity in the field and to then ultimately use this information to improve grassland and livestock management within south-eastern Australia. Furthermore, it is hoped that this study contributes to the further development of research tools that can be applied within native pastures and grazing animals.

1.6 Research questions

Given the lack of knowledge about the nutrition and diet selection of sheep within native pastures the aim of the research reported in this thesis was to answer the following questions for a native grassland in the Central Tablelands of NSW:

How do different grazing systems affect live weight, body condition score and wool production of sheep?

How variable is the composition and quality of the diet of individual sheep?

How does change of season and pasture composition affect diet selection by sheep?

How is diet selection and grazing behaviour of sheep and the physiological state of plants affected by grazing systems?

How is a landscape utilised by grazing sheep?

Is the analysis of faecal samples an accurate and effective method to predict the quality of the diet of grazing sheep?
Chapter 2. Literature Review

The management and nutrition of livestock on native grasslands in Australia has been the subject of research over many years, though much of that has been at a meso-scale with limited consideration of what animals are doing and where. In this chapter the literature is reviewed in terms of the main issues that were addressed in this thesis. These were: i) native vegetation, plant nutrients and the impact of grazing on plants; ii) sheep nutrition and grazing behaviour within native grasslands and pastures; iii) dietary effects on animal performance; and iv) management effects on sheep diet and production.

2.1 Native pastures and grasslands

Native pastures and grasslands dominate the major livestock production areas of the HRZ of south-eastern Australia and are vital in maintaining biodiversity, healthy landscapes and ecosystems (Johnston 1999; Garden et al. 2000; Kemp and Dowling 2000; Dorrough et al. 2008). Native grasslands are often considered to be solely comprised of native grasses and herbs, whereas natural pastures have typically been routinely grazed by stock and are characterised by a complex mosaic of plant species. Natural pastures may include native, introduced and naturalised perennial and annual grasses, legumes and forbs (Whalley and Lodge, 1987) and are a result of succession in a native grasslands caused by increased grazing pressure and fertilisation (Moore 1970). In this thesis these terms are used interchangeably, reflecting common usage. Historically, native grasses were considered to be of low production potential and unable to utilise improved regimens of moisture or nutrients in comparison to introduced species (Donald 1970). As a consequence native grasslands were ‘improved’ by the over-sowing of a legume species such as *Trifolium subterraneum* together with the widespread application of superphosphate fertiliser and thus naturalised pastures are often the result of previous pasture ‘improvement’. The concept that native grasses were of little value in animal production (Donald 1970) appears to be unfounded as studies by Archer and Robinson (1988) and Robinson and Archer (1988) found total production of year-long perennial native grasses (Austrodanthonia linkii, Microlaena stipoides, Poa seiberana) and summer perennial native grasses (Bothriochloa macra, Themeda australis and Sporobolus elongatus) under improved conditions of fertility and moisture...
to be at least equivalent to that of the introduced grass species of *Festuca arundinacea* and *Phalaris aquatica*.

Climatic conditions are a major determinant of plant production and pastures and the temperate perennial C3 grasses *Austrodanthonia* spp. and *M. stipoides* can provide year-round digestible green leaf material and tolerate dry conditions well. *Microlaena stipoides* has high nitrogen (N) and phosphorus (P) concentrations (Robinson and Archer 1998) and the value of the species has been demonstrated by substantial weight gains in sheep and cattle when grazing paddocks dominated by the species (Wyndham 1986). *Austrodanthonia* spp. is considered to be one of the most valuable grasses for grazing (Moodie 1934) due to its ability to withstand heavy grazing and tolerance of dry conditions (Breakwell 1923) as well as its adaptability to a wide variety of environments possibly as a result of the broad genetic base of the species (Scott and Whalley 1984). However, the species has a high proportion of stem material similar to the summer tropical perennial C4 native grass *Bothriochloa macra*, which is similarly drought tolerant. *Bothriochloa macra* and other summer perennial native grasses have high summer growth rates but provide limited forage of poor quality during the remainder of the year, particularly in winter. It is recognised that native pastures are generally lower in nutritional quality than introduced annual pasture species. Furthermore, the plant species diversity within a native pasture will critically influence an animal’s feed intake and nutrition (Wang et al. 2010b). A diverse native pasture dominated by temperate perennials that can grow throughout the year with summer perennial species has a high productivity potential, stability and nutritive value (Archer and Robinson 1988) and increased plant species diversity within a pasture has been associated with a rise in animal production (Pfisterer et al. 2003), related to enhanced forage intake (Wang et al. 2010b).

The growth of native grasses, as with all grass species, occurs in three phases: the first involves a slow initial growth rate followed by the second phase of growth known as the vegetative stage in which the growth and the production of leaves rapidly occurs and plants are highly digestible. The third, reproductive phase involves an increase in the production of stem material, flowers and seeds and a reduction in leaf production (Brougham 1958; McDonald et al. 2002; Saul and Chapman 2002). The first and third phases are characterised by lower rates of leaf production per hectare. The growth phase of a plant influences the nutrients available and an animal grazing within a
heterogeneous native pasture must select their diet from a broad range of vegetation in differing growth phases and nutrient contents.

2.1.1 Plant nutrients
The primary components of a plant may be divided into two categories: cell contents and cell wall constituents. Cell contents include non-structural carbohydrates (NSC) (starches and sugars), proteins, vitamins, minerals, lipids and organic compounds, all of which are rapidly digestible (Mackintosh 1981). In contrast, cell wall contents include structural compounds of fibre (cellulose and hemicelluloses) and lignin that have lower digestibility. The proportion of these components varies with plant species, age and parts, season and soil nutrients. Plants in a vegetative stage of growth are generally highly nutritious and digestible with high concentrations of cell wall contents and comparatively low levels of fibre and lignin. As a plant matures the concentration of structural compounds increases to maintain the structural integrity of a plant, which results in an increase in the tensile strength of the plant and the effort required by an animal to harvest, masticate, ingest (Allison 1985; Laca et al. 2001) and digest (Mackintosh 1981; McDonald et al. 2002) the plant. Sheep are inclined to avoid highly lignified forage and prefer younger plant material with readily digestible energy (Hanley 1982; Provenza 1995).

2.1.2. Impact of grazing on plant growth and production
The process of grazing, considered to be a detrimental process to an individual plant, involves the defoliation and trampling of the plant and leaves which reduces a plant’s photosynthetic area, nutrient distribution and competitive fitness for nutrients, water and light (Trlica and Rittenhouse 1993). The resultant reduction in a plant’s foliage and nutrient distribution can impede a plant’s ability to compete with and to maintain any dominance over less palatable species. Plants respond to grazing in a number of ways and also have chemical and physical properties that prevent grazing known as ‘plant defences’.

2.1.2.1. Plant regrowth following grazing
To some degree the effect of grazing on plant communities may be beneficial in terms of the pollination of flowers, the dispersal of seeds, a reduction in the size of competing plants if damaged and the recycling of soil nutrients via defaecation and urination (Belsky 1986). The effect of grazing, which differs between plant species and individual
plants, may be classified as one of three effects: growth stimulation (McNaughton 1979; Maschinski and Whitham 1989; Dyer et al. 1993); reduced plant vigour, growth and delayed reproduction (Belsky 1986; 1987; Maschinski and Whitham 1989; Painter and Belsky 1993); or no obvious effect where a plant equally compensates for the effect of grazing (McNaughton and Chapin 1985; Maschinski and Whitham 1989). It is generally argued that light grazing is beneficial for plant production and forage quality as young vegetative material replaces the older mature material that is removed (Holechek et al. 2004). However, a plant’s ability to regrow following grazing is primarily determined by the post-grazing residual biomass that includes leaf area and NSC reserves (Booysen and Nelson 1975), root biomass (Hodgkinson and Baas Becking 1977) and the length of rest prior to re-grazing (Saul and Chapman 2002).

The removal of leaves reduces a plant’s photosynthetic area. A plant’s regrowth following grazing may be restricted from both photosynthesis and NSC reserves within the plant and/or plant roots (Hodgkinson 1969). Plant regrowth rate is also affected by the stage of plant growth at the time of grazing, the location and density of growth points (apical meristems) within a plant (Richards and Caldwell 1985), the dormancy of those growing points and the available nutrients within the surrounding environment which affect a plant’s ability to compete with other plants for essential water and nutrients (Hodgkinson and Baas Becking 1977). Following grazing ‘short shoot’ plants including forbs such as Hypochaeris radicata with very low apical meristems (that are typically too low to be removed during grazing) have a greater ability to regrow following grazing than ‘long shoot’ plants such as grasses that grow and elongate from intercallery nodes along their stems (Srivastava 2002), especially during the reproductive phase of growth. In the case of grasses, Hodgkinson and Baas Becking (1977) observed the removal of leaves from Austrodanthonia spp. plants resulted in a depression in root growth and in some cases root death in proportion to the severity of defoliation. In a field study, Hodgkinson (1976) found when defoliation of Austrodanthonia spp. occurred during low soil water availability the depression of root growth could result in plant death and mortality increased as defoliation frequency of the plant increased. When a plant is frequently defoliated less leaf area is available to supply energy through photosynthesis. Any stores of NSC are diminished as is the size and function of the plant’s root system and ability to compete for and absorb essential water and nutrients. This can ultimately result in a severe depression of plant vigour and/or plant death.
2.1.2.2. Plant grazing defences

Pasture species differ substantially in their physical and chemical characteristics. The spatial arrangement of plants and plant parts within a pasture and the production of toxins, alkaloids, tannins and terpenoids (Kumar and Singh 1984) can all deter animal grazing.

The presence of mechanical structures such as spines, thorns, prickles, hairs and awns can deter grazing and reduce an animal’s intake by injuring an animal’s mouth and digestive tract (Adams 2008). Cooper and Owen-Smith (1986) and Gowda (1996) observed that grazing ungulates (impalas and antelopes) and goats consumed greater quantities of the same plants when spikes, thorns and prickles were removed.

The spatial arrangement of a plant within a pasture canopy and the growth form of a plant will influence its accessibility and ‘apparency’ to a grazing animal. At high densities plants may be protected from herbivory by neighbouring plants (Rousset and Lepart 2002) that are of differing chemical components and/or growth form. Grasses with an upright and erect habit and a high density of leaves will be more apparent and accessible in taller swards than plants with a prostrate growth habit such as clovers or flat forbs. However, as a plant matures and grows and as accessibility increases, the fibre and lignin content of the plant also increases. This results in a decline in nutritional value (Nelson and Moser 1994; Lopez et al. 2001) and an increase in the effort required to harvest, ingest and digest the plant, resulting in a limitation of an animal’s intake (Allison 1985). As a plant matures spikelets and burrs are produced during the reproductive phase of growth that can aid the survivability of plants and their seeds (Cooper and Owen-Smith 1986; Gowda 1996). Within south-eastern Australia the awns, spikelets and burrs of *Avena* spp., *Austrostipa* spp., *Bromus* spp., *Hordeum* spp. and *Medicago polymorphia* cause substantial eye, mouth and nose injuries to grazing sheep as well as contamination of fleece and hides. The intake of these species when mechanical structures are present is typically reduced (Loughnam 1964; Hartley 1973).

The chemical composition of a plant and the presence of toxins and other secondary metabolites including alkaloids, glycosides, tannins and terpenoids can affect a plant’s susceptibility to grazing. The presence of secondary compounds can also be a result of the presence of endophytes. These secondary compounds are typically found in shrubs and only a very small number of pasture species. They are often associated with strong odours and unpleasant taste and can reduce the rate of digestion and decrease an
animal’s consumption (Kruegar et al. 1974; Launchbaugh and Dougherty 2007). The concentrations of chemical constituents of a plant, in particular pasture species, are influenced by the growing environment. Plants growing in N deficient soils will generally contain low N concentrations and have been found to be less preferred by sheep than plants growing in soils with higher N concentrations (Forbes and Watson 1992). Sheep prefer plants growing in environments with adequate N in comparison to plants from environments containing excess N as these plants often contain excess nitrates, which become toxic when excessively converted to nitrite in the rumen (Reid et al. 1966; Minson 1973).

The influence of plant characteristics, growth and production are important considerations in understanding the grazing behaviour, location, selection and nutrition of grazing sheep, particularly within heterogeneous landscapes.

2.2. Sheep nutrition in native pastures

Native grasslands and pastures with a range of species can provide green forage throughout the year, depending upon rainfall. Because native grasslands and pastures in south-eastern Australia have traditionally been considered to be of little value in livestock production producers have often managed these pastures as a low input, low output system by grazing non-breeding stock with low nutrient requirements. Animals were typically set-stocked within large areas of these pastures and overgrazing, pasture degradation and soil degradation and erosion as well as a decline in animal productivity resulted (Archer et al. 1993; Kemp et al. 2000; Dorrough et al. 2004b).

The value of natural grasslands and native pastures has been recognised by many producers and the need to maintain and improve the pastures together with declining terms of agricultural trade have resulted in a shift towards the sustainable management of these pastures whilst maintaining the productivity of sheep grazing these pastures (Kemp et al. 2000). In order to improve animal production within these pastures knowledge of the nutrient requirements of the animals is essential.

2.2.1. Ruminant nutrition

The essentials of ruminant nutrition are: energy (primarily in the form of starches and carbohydrates), N, sulphur (S), minerals and vitamins that are vital for the health and function of rumen microbes and the host animal itself.
Cellulose, complex sugars and protein of forages ingested by sheep are fermented in the rumen by microbes (primarily bacteria and some protozoa). The end-products of fermentation are volatile fatty acids (VFA) that are used by the bacteria to grow and multiply and also provide energy to the sheep. Up to 80% of an animal’s energy requirements can be supplied by VFA (Egan 1980), with the primary sources of energy being acetate, propionate and butyrate. Acetate and butyrate are precursors for lipid production and propionate is important for glucogenesis (Forbes 2007).

Rumen bacteria synthesise (from dietary N sources) microbial protein that is subsequently utilised by the host animal. Rumen microbes account for more than 50% of the amino acids that are absorbed in the small intestines and converted to protein (McDonald et al. 2002). Other products of microbial synthesis that are beneficial to sheep are synthesised B-complex and K vitamins (ASIA 2002).

The diet selected by a grazing sheep generally meets their nutrient requirements (Arnold 1981). This is thought to be driven by a balanced intake of nutrients (Westoby 1974) in particular, energy and protein (Egan 1977) that results in the maintenance of a balanced rumen environment, i.e. one where the nutrient requirements of the rumen microbes are met (Forbes 2007). Kyriazakis and Oldham (1993) observed that lambs selected feeds that provided a balance of nutrients (protein and energy) in preference to feeds that supplied either excessive or insufficient energy and/or protein. Similarly, Scott and Provenza (1999) observed lambs fed a low-protein diet actively ‘compensate’ by consuming more of a feed high in protein in comparison to lambs fed a diet of adequate protein. The intake of a balance of nutrients is driven by metabolic signals (known as post-ingestive feedback) that depress selection and intake when nutrients are either inadequate or excessive (Provenza 1995). Post-ingestive feedback is important in the development of food preferences and aversions and the diet selection of an animal differs according to the animal’s physiological and metabolic state together with associated hormonal and chemical factors that alter an animal’s satiety threshold and intake (Freer 1981). Intake is also regulated by post-ingestive signals of rumen fill and the quantity of fermentation products and nutrients (Baumont et al. 2000). Selection is modified by the availability and palatability of forage and is influenced by the grazing behaviour of the animal.
2.3 Grazing behaviour of sheep

2.3.1 Palatability and selection

Palatability refers to physical and chemical plant characteristics that are ‘attractive’ or ‘acceptable’ to an animal (Heady 1964) and incorporates the animal’s sensory perception, in particular taste (Arnold 1966a; 1966b; Kruegar et al. 1974) and to a lesser degree smell, which reinforces taste (Bell 1959). The palatability of a plant is affected by the plant species (Minson 1981), plant parts (Arnold 1964; Minson 1981) and the stage of maturation (Cordova et al. 1978; Burns et al. 1989). Plant nutrients including sugars and soluble carbohydrates (Cowlinshaw and Alder 1960; Gangstad 1964; Heady 1964; Reid et al. 1966), protein and N (Blaser et al. 1960; Gangstad 1964; Heady 1964) and minerals (Cook 1959; Cowlinshaw and Adler 1960; Gangstad 1964) all increase a plant’s palatability. Whereas the presence of fibre and cell wall contents (Blaser et al. 1960; Arnold 1964; Gangstad 1964; Heady 1964), mechanical structures such as thorns and awns (Cooper and Owen-Smith 1986; Gowda 1996) and toxins (Burritt and Provenza 2000) have been negatively correlated with palatability. Clover species with high concentrations of N and readily digestible starches and sugars together with a higher leaf to stem ratio and lower fibre content are considered to be more palatable than grasses in a similar stage of development. The greater palatability of clover is attributed to the consistent consumption of more clover than grass (average ratio 70:30) by sheep grazing adjacent monocultures (Parsons et al. 1994; Newman et al. 1994; Penning et al. 1995; Rutter 2006). A plant’s palatability varies according to the environmental variables of climate, topography and soil moisture (Cook 1959) and between plant parts and as a plant grows and matures. Younger plants are more palatable than mature plants (Nelson and Moser 1994) and leaves are more palatable than stems (Arnold 1964). Palatability is a key factor in an animal’s preference for particular plants and preference is both a relative term and a complex phenomenon. Preference has been described as involving the integration of a plant’s palatability with an animal’s digestive experience (metabolic feedback), previous grazing experience, physiological state and nutrient requirements (Provenza 1995).

Underlying an animal’s preference is the maintenance of a balanced rumen environment, the most efficient intake of energy and a balance of nutrients (Westoby 1974). This balance of nutrients is primarily a balance of energy and protein (Egan 1977) which in part explains the diurnal variation in the preference of grazing sheep for
clover in the morning and grass later in the day and evening (Parsons et al. 1994; Rutter 2006). The selection of grass later in the day is associated with an increase in water soluble carbohydrate content during the day to provide a greater balanced supply of nutrients in comparison to the consumption of grass earlier in the day (Orr et al. 1997).

The diet selected by a grazing animal is a function of preference and the plant species and plant parts consumed by an animal is influenced by the proportion and distribution of preferred components within a canopy and sward (Hodgson 1979). Diet selection varies between individual animals and is influenced by an animal’s previous grazing experience (Arnold 1964; Arnold and Maller 1977; Ortega-Reyes and Provenza 1993; Olson et al. 1996). Highly preferred plants are often continuously re-grazed as animals consume the palatable vegetative re-growth (Norton 1998) before consuming less preferred species in response to a decline in availability of preferred plants (Rosiere et al. 1975). The spatial distribution and arrangement of preferred plants within a pasture are a significant challenge to a grazing animal within heterogeneous environments and pastures. Plant distribution influences diet selection (Dumont and Gordon 2003) and thus movement of animals within these landscapes, resulting in spatially uneven grazing (Senft et al. 1987; Bailey et al. 1996; Baumont et al. 2000; Parsons and Dumont 2003; Rutter 2007).

2.3.2 Spatial variability of grazing

The spatial distribution of food resources is an important factor affecting animal grazing behaviour (Wang et al. 2010a). Predicting diet selection of grazing animals is complex in heterogeneous native pastures where animals face the challenge of ingesting a diet of maximal quality and adequate quantity (Senft et al. 1987). Spatially diverse landscapes together with the diet selectivity of sheep result in the uneven use of a landscape and as a consequence the uneven distribution of nutrients within the landscape that can have a profound effect on sward composition and production (Adler et al. 2001; Soder et al. 2007; Oom et al. 2008).

Grazing sheep exploit heterogeneity by grazing selectively. Typically they select high quality plant materials (Jamieson and Hodgson 1979) and consume a diet of higher nutrient quality than the average pasture (Baumont et al. 2000). The grazing process, which includes how animals perceive landscapes and plants and make decisions, has been described by Senft et al. (1987) and Bailey et al. (1996) using hierarchical models. According to these models an animal firstly selects a site of grazing, and then selects a
grazing patch within the site. Here the animal then exerts selection species by species, plant by plant including the selection of specific plant parts (Senft et al. 1987; Bailey et al. 1996; Bailey 2004).

A greater understanding of the location of animal grazing and the influence of landscape and vegetation has been explored via the use of global positioning systems (GPS) collars in sheep (Rutter et al. 1997; Oom et al. 2008; Umstätter et al. 2008; Taylor et al. 2011) and cattle (Bailey et al. 2004; Schlect et al. 2004; Ganskopp and Bohnert 2006; 2009; Putfarken et al. 2008; Handcock et al. 2009). Studies of animal behaviour (Umstätter et al. 2008; Ganskopp and Bohnert 2009; Handcock et al. 2009) in combination with landscape and vegetation maps using geographical information systems (GIS) data and/or satellite remote sensing using normalised difference vegetation index (NDVI) have provided further detail of factors that may influence the landscape use of grazing animals. The remote monitoring of animal location, behaviour and landscapes (Rutter 2007) and the detailed study of pastures and landscapes and animal location and behaviour via traditional methods have found the location and choice of grazing site by an animal are affected by a multitude of vegetation and landscape effects. Vegetation characteristics that have been found to affect the location and behaviour of grazing animals include species composition (Illius et al. 1992), forage quality, plant morphology and height (Bailey et al. 1996), plant productivity (Hodgson, 1985; Bailey et al. 1996) as well as the distribution of preferred plant species (Illius et al. 1992; Edwards et al. 1996; Clarke et al. 1995; Dumont et al. 2000; 2002; Ganskopp and Bohnert 2006) and non-preferred plant species (Wang et al. 2010a). An animal’s choice of grazing location is also affected by the landscape, topography and slope (Valentine 1947; Baumont et al. 2000; Bailey et al. 2004; Thomas et al. 2008) that in turn determine microclimate effects, predation risk and plant growth (Coughenour 1991). Grazing location relates to proximity to water (Valentine 1947; Squires 1976; Baumont et al. 2000; Bailey et al. 2004; Thomas et al. 2008), shelter (Taylor et al. 1987; Baumont et al. 2000; Taylor et al. 2011) and social factors (Penning et al. 1993; Dumont and Boissy 2000; Boissy and Dumont 2002).

The selection of an animal’s grazing location is influenced by an animal’s preference for areas of high forage quality and quantity (Kenney and Black 1984; Senft et al. 1987; Bailey et al. 1996) that is modified by visual cues (Bazley 1990) together with an animal’s memory and learning (Edwards et al. 1997; Dumont and Petit 1998). The
movement of animals between locations is related to forage depletion at the grazing site; described by Charnov (1976) as the marginal value theorem and validated by Demment et al. (1993) and Laca et al. (1993) in cattle. The effects of landscape variability and vegetation diversity on animal grazing behaviour and performance are not well understood (Soder et al. 2007) and may be explored via the investigation of the diet of sheep grazing within heterogenous landscapes and pastures.

2.4 Determining the diet of grazing sheep

Determining the diet of grazing ruminants is a major challenge. The primary determinants of an animal’s production are diet quality, diet composition and feed intake.

2.4.1 Diet quality

The quality or chemical composition of the diet of an animal is determined by the supply of nutrient and energy obtained and measured as the digestibility (%), metabolisable energy (ME) (MJ/kg DM) crude protein (CP) (g/kg DM) and fibre (g/kg DM) content and to a lesser degree the mineral and vitamin contents.

The chemical composition of an animal’s diet may be estimated from animal based methods including the analysis of diet samples collected from oesophageal or ruminally fistulated animals and collected faecal samples or plant-based methods such as harvested plant material representative of the animal’s diet. Samples collected from fistulated animals are considered to be the more accurate method of assessing diet quality (Holechek et al. 1982a). However, samples from fistulated animals are limited to short periods of time and can interfere with an animal’s normal grazing behaviour and selection (Kiesling et al. 1969; Coates et al. 1987; Mayes and Dove 2000).

Furthermore, the use of fistulated animals is limited in extensive grazing situations and by practical and welfare concerns (Le Du and Penning 1982). A non-invasive method of estimating the chemical composition of a grazing animal’s diet is the chemical analysis of hand plucked samples that are representative of the animal’s diet (Kiesling et al. 1969; Langlands 1974; Wallis De Vries 1995). The method is inexpensive and hand-plucked samples are free from contaminates associated with oesophageal extrusa and rumen samples (Wallis De Vries 1995). However, the accuracy of the technique varies between operators (Kiesling et al. 1969) and was found to underestimate and overestimate the digestibility and N content of the diet of grazing sheep for low quality
and high quality herbage, respectively (Langlands 1974). Furthermore, the method requires knowledge of the animal selection and is laborious and tedious (Gordon 1995; Ben Salem and Papachristou 2005).

Faecal analysis is an alternate method that allows the examination of large numbers of easily obtained samples without disruption to grazing animals via faecal indices and near infrared reflectance spectroscopy (NIRS) analysis.

An important factor in diet quality is digestibility, as a feed’s digestibility affects the rate of passage and thus affects an animal’s intake. Digestibility is a measure of the extent to which a feed is retained and utilised by an animal. Digestibility decreases as fibre content increases, in particular with plant maturation (Duru et al. 1999; Lopez et al. 2001). Determining the digestibility of an animal’s diet is a primary concern as digestibility and ME of a diet are linked and ME can be estimated directly from the digestibility value (Court et al. 2010).

2.4.1.1 Determining the digestibility of the diet

The true digestibility of a feed has traditionally and accurately been determined by in vivo metabolism studies that require the confinement of animals and the measurement of total feed intake and total faecal and urinary output. These studies are specific to the studied animal species due to differing digestive abilities of ruminant species (Huston et al. 1986) and are laborious, tedious, time consuming and expensive (Givens and Deaville 1999). Alternative laboratory methods of wet chemistry analyses have been developed that mimic in vivo digestibility and fermentation and allow the rapid and more economical analysis of pasture and diet quality. The most commonly used in vitro method of determining the digestibility of feeds and diets (from oesophageal fistula samples and pasture samples) is the modified, two-stage method developed by Tilley and Terry (1963). The method requires a supply of fresh ruminal fluid from fistulated animals to estimate in vivo digestibility of a sample using regression equations derived from metabolism studies and a broad range of forages (Armstrong et al. 1989).

Alternate less invasive methods that may provide estimates of diet digestibility are the analysis of faecal (chemical) indices and the analysis of forage and faecal samples using NIRS.
2.4.1.2 Faecal indices

The potential of faecal indices as a method to estimate diet quality was identified by Holechek et al. (1982a) who found faecal indices were more closely related to organic matter (OM) intake and animal live weight gain than fistula samples in cattle grazing mountain range pastures. Faecal indices have been used to predict diet digestibility, quality and intake in sheep (Wehausen 1995; Boval et al. 2003; Wang et al. 2009), cattle (Holloway et al. 1981; Holechek et al. 1982a; Wehausen 1995; Lukas et al. 2005) and deer (Mubanga et al. 1985; Hodgman et al. 1996; Kamler and Homolka 2005).

Holloway et al. (1981) investigated the relationship between faecal components and diet intake and digestibility of cattle (n = 39 observations) fed grass and legumes (Trifolium incarnatum, Trifolium pratense and Lespedeza stipulacea). Associations were identified between faecal N (fN) and dry matter (DM) digestibility (DMD, R² = 0.67) and fN and digestible DM intake (R² = 0.66). The authors concluded the application of faecal indices is limited by seasonal changes in forages and by differing qualities between forage species. But the development of broadly applicable predictive equations using faecal indices is possible for different classes of a species of livestock provided equations are derived from data that includes forages from different seasons as well as relevant pasture species.

Holechek et al. (1982a) investigated relationships between animal performance, intake and diet quality and faecal indices in oesophageal-fistulated cattle grazing mountainous pasture (n = 40 observations). Strong correlations were identified between fN and diet N (R² = 0.83) and faecal sample in vitro digestibility and diet in vitro digestibility (R² = 0.71) and a multiple regression equation using both fN and faecal sample in vitro digestibility improved the prediction of diet in vitro digestibility (R² = 0.83). Correlations were also identified between average daily live weight gain, OM intake, fistula sample in vitro OM digestibility (OMD), fistula sample N, faecal sample in vitro digestibility and fN. However, similar to Holloway et al. (1981) the authors conceded the application of the derived equations is limited to similar pasture composition as evident by the precision of the correlations being substantially reduced by high forb and/or browse components within the diet.

Nunez-Hernanez et al. (1992) evaluated faecal indices as predictors of diet intake, N balance and digestible OM intake in cattle (n = 32) and goats consuming diets of forbs, shrubs and alfalfa (lucerne) hay. Using multiple regression equations fN output and fN
content were associated with N intake of cattle ($R^2 = 0.91$) and goats ($R^2 = 0.97$). However, the authors concluded $f/N$ parameters were limited as indicators of ruminant protein status when abrupt changes in botanical composition occurred and the derived equations were specific to each ruminant species and studied pasture.

An earlier study by Leite and Stuth (1990) assessed the use of $f/N$ fractions and condensed tannins to predict the dietary CP, *in vitro* OMD and intake of steers grazing a rangeland ($n = 287$ observations). A strong relationship was identified between total $f/N$ output and OM intake ($R^2 = 0.84$). However, no individual parameter was highly correlated with diet variables. Derived multiple regression equations to predict dietary CP (%) ($R^2 = 0.57$) and CP intake ($R^2 = 0.51$) while being significant were of limited value due to the low correlation coefficients. The authors concluded the use of multiple faecal indices were of limited use in predicting diet quality parameters. The poor correlation between diet and faecal parameters was likely to be a result of the presence of dietary tannins identified later by Wehausen (1995). Wehausen (1995) evaluated faecal indices in sheep and cattle using an algebraic model to predict the diet attributes predicted by faecal parameters of sheep and cattle consuming grass and grass and alfalfa diets. A curvilinear relationship was identified between apparent digestibility and $f/N$ in sheep and cattle consuming grass diets and alfalfa diets. However, the same relationship did not exist when diet N was indexed to $f/N$ in sheep consuming an alfalfa diet. The authors concluded the relationship between $f/N$ and diet parameters was confounded by the presence of dietary tannins that reduced protein digestibility.

Boval *et al.* (2003) examined faecal CP ($f/CP$), neutral and acid detergent fibre (NDF and ADF) and acid detergent lignin (ADL) content as predictors of OMD of the diet of sheep ($n = 40$ observations) (and goats) fed a tropical pasture monoculture (*Digitaria decumbens*). The prediction of diet OMD from $f/CP$ had the lowest residual standard error ($R^2 = 0.74$) of the tested faecal parameters and was considered to reliably predict the OMD of sheep (and goats) consuming the same pasture. Wang *et al.* (2009) investigated the predictive ability of $f/CP$ and faecal acid detergent soluble CP to develop predictive regression equations of dietary OMD of sheep consuming forage based diets. In contrast to the previous studies the authors used data derived from 150 *in vivo* digestibility studies ($n = 721$ observations) that incorporated forages from Germany and Inner Mongolia (China) and included fresh grass, grass silage, alfalfa silage, soybean concentrate and *Leymus chinensis*, *Stipa grandis* (common C3 grasses of the
Eurasian steppe) and *Artemisia frigida* (common forb). The authors derived an equation to predict the diet OMD from fCP that slightly underestimated OMD. However, as this effect was marginal the authors suggested the equation may be used to predict the OMD of forage ingested by sheep grazing heterogeneous pastures.

Mahipala *et al.* (2009) investigated the ability of faecal composition to predict diet nutritional characteristics of sheep consuming diets of oaten hay (*Avena sativa*) and tannin-containing browse that included *Acacia saligna, Chamaecytisus palmensis* and *Atriplex amnicola* (n = 174 observations). Multiple regression equations identified strong correlations between faecal indices and total phenolic content ($R^2 = 0.89$) and total tannin content ($R^2 = 0.87$). Faecal indices were correlated with the diet parameters (determined from the *in vitro* gas production of feed samples) OMD ($R^2 = 0.78$), short chain fatty acid production ($R^2 = 0.78$) and ME ($R^2 = 0.78$). Poor correlation between diet CP and faecal parameters were observed and may be attributed to the presence of tannins, similar to Wehausen (1995) and suggested by the data obtained by Leite and Stuth (1990). In light of the strong correlations between faecal and diet parameters the authors conclude the derived equations can predict the diet quality of browse-containing diets and similar to Wang *et al.* (2009) suggest the equations have broader application as a diet quality predictor in other pastures.

The common similarity of the prediction of diet quality from faecal indices reported in the previous studies was that trends in faecal composition were associated with and confounded by diet quality factors and predictive equations were specific to each situation in terms of pasture composition, presence of tannins, season, animal species and class. Two exceptions were the equations developed by Wang *et al.* (2009) and Mahipala *et al.* (2009). The predictive equations of Wang *et al.* (2009) were developed from a wide variety of plant species and seasons and an extensive number of observations. Similarly, the predictive equations of Mahipala *et al.* (2009) were derived from a number of different species, numerous observations and recorded very high correlations between faecal and diet parameters. The development of specific regressions for each pasture study and composition is limited by cost, time and labour constraints thus the broader application and validation of derived predictive equations is worthy of investigation.

A critical consideration of the broader application (and potential validation) of derived equations to estimate diet quality from faecal indices in different areas and pastures is
whether the variation in diet quality and faecal parameters encountered in the developed
equations are appropriate (or broad enough) for the different pasture encountered by the
animals. In a critical review of faecal indices Hobbs (1987) suggested that a quantitative
comparison of diet quality from broader (or potentially ‘generic’) equations may not be
possible; however, qualitative comparisons may be.

2.4.1.3 NIRS analysis of feed and faecal properties
The application of NIRS in the direct analysis of the nutritive value of forages and
concentrates is widespread (Shenk and Westerhaus 1994). The major benefits of NIRS
are the rapid and economical analysis of a large number of samples that requires no
reagents or potential safety hazards (Mark et al. 2002). The benefits of NIRS analysis
together with relationships identified between an animal’s diet and faecal chemistry
(faecal indices) have led to the use of NIRS as an indirect method of estimating diet
quality via faecal analysis or profiling known as faecal NIRS (fNIRS). Using fNIRS
together with oesophageal extrusa samples Lyons and Stuth (1992) found the in vivo
digestibility of the diets of cattle grazing grass and shrub land sites could be estimated
with an accuracy similar to conventional wet chemistry methods. Similarly, Gibbs et al.
(2002) predicted the DMD and CP content of the diet of cattle fed supplements via
fNIRS calibration equations derived from pen-feeding studies. The authors later
estimated the microbial protein production of grazing cattle from fNIRS (Gibbs et al.
2004). The principles, procedures and development of calibration equations for fNIRS
are similar to the NIRS analysis of the nutritive value of forages.

NIRS is the analysis and characterisation of a sample based upon the absorption
properties of the sample within the near infrared reflectance (NIR) radiation region (750
– 2500 nm). The NIR spectrum of a forage or faecal sample is related to the chemical
bonds within the OM and includes primarily carbon (C), hydrogen, N and oxygen
(Givens and Deaville 1999). The technique relies upon empirical calibration equations
that relate the NIR spectra of a pasture or faecal sample to reference values determined
by laboratory ‘wet chemistry’ methods, to then estimate the sample’s nutrient content
(Hruschka 1987; Deaville and Flinn 2000). The accuracy of NIRS analysis is influenced
by wave length selection (Hruschka 1987; Williams 1987) and the mathematical method
of calibration development and the number and range of samples in a calibration dataset
(Shenk and Westerhaus 1994; Givens and Deaville 1999). The number of samples and
diversity of samples required in the development of a calibration equation is dependent
upon the use and application of a calibration. Calibration models for plant and/or faecal samples for a single plant species or simple pastures is relatively straightforward and more accurate than ‘wide’ calibration equations that are designed to encompass a wide spectral variety (Landau et al. 2006) typically associated with complex pastures and grazing animals.

The applicability and accuracy of NIRS equations can be evaluated using the statistical parameters of $R^2$, standard error of cross validation (SECV) and the standard error of reference database to standard error of cross validation ratio (RPD ratio). According to Williams (2004), to be acceptable an NIRS equation must have an $R^2$ greater than 0.80, a SECV close to the standard error of calibration (SEC) and an RPD ratio greater than 3. Equations for use within complex pastures require extensive calibration datasets that incorporate factors such as; numerous pasture species, differing phenological stages, seasons, geographical locations and soil types that reflect possible sources of variation likely to occur in future samples (Deaville and Flinn 2000).

The development of $f$/NIRS calibration equations are dependent upon the matching of diet and faecal samples from a diverse range of forages. The primary source of data for the development of earlier $f$/NIRS calibration equations were pen-feeding trials typically involving the feeding of hay. Coates (2000) found the applicability of these equations to grazing animals to be limited, which led to the development of calibration equations from feeding studies of fresh forage consumed by cattle (Coates 2000) and sheep (Fanchone et al. 2007) to be more accurate.

To date $f$/NIRS studies in sheep have included digestibility studies (Li et al. 2007b; Decruyenaere et al. 2009; Fanchone et al. 2009, Kumara Mahipala et al. 2010) and CP concentration studies (Fanchone et al. 2007). The NDF and ADF (Fanchone et al. 2007) content of sheep diets have also been predicted by $f$/NIRS as has the N and carbohydrate fractions in the diet of dairy sheep (Decandia et al. 2009).

Substantial time and expense is associated with the establishment of $f$/NIRS calibration equations and with the exception of the potential development of a global calibration by Decruyenaere et al. (2009) using data from 142 digestibility trials (and a total of 1034 feed and faecal pairs) developed equations are typically limited to the particular region, season, animal and forage species and specific diet compositions (Coates 2000). Fanchone et al. (2009) compared the accuracy of $f$/CP and $f$/NIRS and found $f$/CP accurately estimated diet OMD with small datasets ($n = 40$) whereas $f$/NIRS more
accurately estimated diet OMD when larger datasets (n = 84 and n = 174) were available. Thus the use of a method is dependent on the circumstances and data available. Provided appropriate, precise and effective calibration equations are available or developed, NIRS is considered to be an accurate and efficient method (Lyons and Stuth 1992). The analysis of samples using NIRS allows the rapid and economical analysis of a large number of samples and in some situations has the potential to estimate the diet composition of grazing animals.

2.4.2 Diet composition
The botanical composition of a grazing animal’s diet may be estimated using one or a number of techniques in combination. The majority of techniques have been developed in simple pastures and the applications of these methods in heterogenous pastures and an extensive grazing situation rely upon a combination of methods.

2.4.2.1 Observation methods
The direct observation of the selection of grazing animals allows the collection of large amounts of detailed information (Hobbs et al. 1983) and has been successively used in grazing sheep and goats (Ngwa et al. 2000) and goats and llamas (Dumont et al. 1995). However, the technique is time consuming and tedious and the validity, accuracy and precision of the data is questionable and typically biased towards easily observable plant species (Gordon 1995; Ben Salem and Papachristou 2005). The presence of an observer can interfere with an animal’s normal behaviour and selection and night-time observation is difficult. An alternative means of estimating diet composition involves measuring the pre- and post-grazing pasture biomass and composition.

Direct visual estimation (Campbell and Arnold 1973) and BOTANAL assessment (t’Mannetje and Haydock 1963; Tothill et al. 1992) allow the rapid assessment of pasture biomass (kg DM/ha) and botanical species composition to determine the preferred plant species over a short period of time (Dowling et al. 2005). Samples sizes, frequency of monitoring and size of quadrats must be appropriate to the area size and pasture of study (t’Mannetje 2000). The accuracy of visual estimation declines as herbage biomass increases and it is difficult to detect changes in biomass when minimal utilisation (less than 0.5 t/ha) has occurred (Frame 1993). As a consequence within heterogeneous pastures large sample sizes are necessary.
2.4.2.2 Identification of plant material in oesophageal, rumen and faecal samples

The composition of the diet of grazing animals has been estimated by the microscopic examination of oesophageal fistula samples (Rosiere et al. 1975; Squires and Low 1987), rumen samples (Mayes and Dove 2000) and faecal samples (McInnes et al. 1983; Alipayo et al. 1992). McInnes et al. (1983) found the estimated intake of grasses and forbs from the examination of faecal and rumen material was limited by the high proportion of faecal sample material that could not be identified. The accuracy of estimating diet composition from plant material identification in samples is further dependant on systematic training and practice by the observers for the studied pasture (Alipayo et al. 1992) which is costly and time consuming. Examination of oesophageal samples is considered to be the more accurate method (Rosiere et al. 1975); however, fistulated samples are limited to short periods of time and by animal welfare considerations. Alternate less invasive techniques of estimating the diet composition of grazing animals include the analysis of plant cuticle hydrocarbons, DNA fingerprinting and faecal fNIRS.

2.4.2.3 Analysis of plant and faecal hydrocarbons

Alkanes are saturated hydrocarbons in the cuticular waxes of plants. The concentration and profile of alkanes are specific to plant species and plant parts (Dove et al. 1996; Ferreira et al. 2005). The use of alkanes and dosed markers allows the simultaneous estimation of both the composition and intake of the diet and thus removes the need for fistulated animals (Mayes and Dove 2000). The alkane technique requires analysis of plant and faecal samples and the application of the technique has been successfully validated in pen feeding studies with sheep (Lewis et al. 2003; Valiente et al. 2004), goats (Ferreira et al. 2005), cattle (Ferreira et al. 2007a) and horses (Ferreira et al. 2007a). In contrast to pen-feeding studies the diet selection of grazing animals is associated with large errors and greater variability (Mayes and Dove 2000) and the use of the technique has only been validated in simple pastures of grass, grass and clover and grass and browse mixtures (Newman et al. 1995; Chen et al. 2002; Celaya et al. 2007). The use of alkanes is limited in complex grazing situations due to the limited number of available alkanes as markers in comparison to the large number of botanical components within heterogenous pastures (Dove 1996; Fereria et al. 2007b; Oliván et al. 2007; Valiente et al. 2004) and often insufficient differences in the concentration and
profile of alkanes between pasture species (Lee and MacGregor 2004). Thus, the use of alkanes to determine the diet composition of grazing animals is presently limited to simple pasture compositions and is considered unsuitable for use in animals grazing complex pastures. An alternative to the alkane technique may be the use of \( f \text{NIRS} \) (Givens and Deaville 1999).

2.4.2.4 Faecal NIRS analysis

The application of \( f \text{NIRS} \) to determine the diet composition of grazing animals is limited. The primary method of estimating diet composition via \( f \text{NIRS} \) is based upon the analysis of n-alkanes concentration in forages and faeces in sheep (Keli et al. 2008) and cattle (Garnsworthy and Unal 2004) grazing simple pastures. Coates and Dixon (2008) found \( f \text{NIRS} \) to be an effective method of estimating the proportions of C3 (non-grass, browse species) and C4 (grass species) plants in the diet of cattle grazing in northern Australia. Walker et al. (1998) and Walker et al. (2002) using \( f \text{NIRS} \) predicted the percentage of leafy spurge and sagebrush, respectively in the diet of sheep and Glasser et al. (2008) determined the diet composition of goats grazing a Mediterranean shrub land.

The application of this technique is limited to pastures of similar grass and browse-species composition and is not applicable to grazing studies in diverse native pastures and grasslands.

2.4.3 Feed intake

The most accurate method of determining feed intake involves giving an animal a known quantity of feed and measuring the quantity of feed remaining, as is used in pen-feeding studies. However, measuring the feed intake of a grazing animal is very difficult and is affected by species of animal (Hanley 1982; Holechek et al. 2004), breed (Brand 2000), live weight (Gunn et al. 1991; Adams et al. 2002), physiological state (Arnold and Dudzinski 1967; Parsons et al. 1994; Penning et al. 1995), diet (Milne et al. 1981; Ketelaars and Tolkamp 1992; Dulphy and Demarquilly 1994; Adams et al. 2002) and forage availability (Allden and Whitaker 1970). Techniques to determine the intake of grazing animals are limited by any method that restricts the animal’s normal grazing behaviour and that removes ingested forage from an animal such as oesophageal and rumen fistulas as changes in the rumen fill of an animal will affect intake (Weston 1966; 1967; 1968). Feed intake of grazing animals can be estimated by direct and indirect
measurements that have varying degrees of error (Minson 1990; Owens and Hanson 1992).

2.4.3.1 Direct measurements of intake
The feed intake of a grazing animal may be estimated by animal and plant based methods, both of which are limited to short-term duration studies. An animal’s intake can be estimated by changes in live weight during feeding (Horn and Miller 1979) and before and after feeding (Le Du and Penning 1982; Penning and Hooper 1985). However, this technique is limited to short durations and the accurate estimation of weight losses from defecation, urination and water loss.

An alternate plant based method of determining feed intake is the difference in herbage mass before and after grazing (Walters and Evans 1979) adjusted for the number of animals and days of grazing. This technique is limited by the accuracy and precision of herbage mass estimates and can lead to overestimations of intake if trampling of forage by animals is not considered and underestimations of intake when growth of forage is not accounted for over extended grazing periods (Burns et al. 1989). Furthermore, the application of estimating intake from differences in herbage mass is limited to small areas due to the intensive sampling required to provide an adequate estimate of changes in herbage mass using non-destructive methods (refer to Section 2.4.2.1 for further details).

As a result of the complexity and constraints of predicting the intake of grazing animals, estimations are commonly derived from indirect methods that involve a combination of techniques that measure diet composition and/or quality as well as total faecal output.

2.4.3.2 Indirect measurements of intake

2.4.3.2.1 Faecal collections
An animal’s intake can be estimated from an animal’s faecal output (and the prediction of faecal quality and quantity) together with the estimation of the digestibility of the diet. The direct measurement of the total faecal output of a grazing animal can be achieved by the use of a harness and collection bags. However, disadvantages of the method include errors resulting from incomplete collection of faeces, the distortion of hind legs due to the weight of faeces in the bag and the resulting effect on grazing behaviour (Armstrong and Eadie 1977). Alternatively, faecal output can be estimated indirectly from the analysis of the concentration of indigestible markers (Doyle et al.
1994) and alkanes (Mayes and Dove 2000) in faeces together with an estimation of diet digestibility. The accuracy of the method may be affected by diurnal variation in marker concentration; continuous release of a marker may reduce this error but is typically expensive and can involve surgery (Corbett 1978; Brandyberry et al. 1991). Markers may be administered as a single dose or a daily or twice daily dose over a number of days. The administration of a marker requires the restraint and handling of the animals that can impact behaviour and intake, a further limitation of the method is the time and labour required to collect numerous samples daily (Holleman and White 1977).

2.4.3.2.2 Diet digestibility and composition estimations

Feed intake has been estimated from measurements of diet digestibility and composition that include observational studies and the hand plucking of representative samples, the analysis of faecal indices, plant and faecal alkanes and fNIRS (that have been outlined previously in Sections 2.4.1.2 and 2.4.3). Intake has also been estimated from studies of an animal’s grazing behaviour.

2.4.3.2.3 Grazing behaviour studies

An animal’s intake is the product of bite size, bite rate and grazing time (Allden and Whittaker 1970; Hodgson 1982). Observation studies have traditionally provided the estimates of these parameters and have been improved by the development of automated methods of recording during observational studies (Demment and Greenwood 1987) and alternate automated techniques. The bite rate of animals can be estimated by automated methods that include bite count meters and vibrarecorders that estimate the short-term bite rate of animals (Stobbs 1970; Chacon and Stobbs 1976; Phillips and Denne 1988) and animal activity monitors (Scheibe et al. 1998) and wireless bite meters (Umemura et al. 2009). Grazing time can be calculated from the analysis of data recorded by GPS tracking devices that allow the continuous monitoring of animal activity and location (Umstätter et al. 2008; Ganskopp and Bohnert 2009; Handcock et al. 2009). The major factor limiting the estimation of intake from grazing behaviour studies is accurately quantifying bite size, which is considered to be a greater source of variability than grazing time and rate (Stobbs 1973; Chacon and Stobbs 1976; Hodgson 1981).

Estimating the intake of grazing animals is inherently difficult and current methods generally lack accuracy and precision and can be laborious and tedious. However,
despite these challenges, greater knowledge of the feed intake, diet quality and composition of grazing animals is essential due to the strong influence of these parameters on animal production.

2.5 The effect of diet on sheep production
The quality and intake of a diet determines an animal’s production in terms of live weight (Arnold 1964), reproduction (Gunn et al. 1991) and wool growth (Coop 1953; Allden 1979; Ferguson et al. 2011). A low quality diet is associated with low live weight gain and body condition score (BCS) as well as reduced wool growth (Chen et al. 2002; Noad 2003). As a result the quality of the diet consumed by an animal can be associated with measured production parameters. However, both animal and wool production are also affected by breed of sheep, age, pregnancy, lactation, climatic and seasonal factors.

2.5.1 Animal live weight and body condition score
Measuring live weight is the simplest and most effective method of determining animal production and condition. However, live weight can be confounded by conceptus effects in late pregnancy and when gut fill differs between weighings. In these situations the assessment of an animal’s BCS (Jefferies 1961) is a more accurate measure (Suiter 1994; van Burgel et al. 2011) particularly over the medium-term. Variation in the live weight of grazing sheep has been associated with annual rainfall and resulting seasonal changes in green DM availability and forage nutritive quality (Arnold 1964; Wilson et al. 1969; Thompson et al. 1994; Freudenberger et al. 1999; Holst et al. 2006).

2.5.2 Wool growth and production
Wool staple length, strength and diameter are highly correlated to an animal’s diet (Sharkey et al. 1962; Nagorcka 1977; Reis 1979; Friend and Robards 2006) and are influenced by the composition and total amino acids (AAs) available from dietary intake and body protein degradation as well as the partitioning of AAs to wool follicles (Masters et al. 1998) and an animal’s metabolic efficiency (Allden, 1979).

The quantity and composition of available AAs are major determinants of wool production (Reis 1979) and high quality diets with high levels of digestible protein are associated with increased wool production (Li et al. 2007a). The composition (and digestion) of protein is an important consideration as protein also supplies energy and the rate of wool growth is influenced by the quality of protein and the supply of ME
(Allden 1979; Williams, 1991). Reis et al. (1992) investigated the effect of varying protein and energy intakes on wool production and found increased protein intake resulted in greater wool growth, whereas an increase in energy intake only resulted in higher wool growth when protein intake was high. These results explained observations of Ball et al. (1972) who found no effect on wool growth when the energy intake of sheep was increased without altering rumen fermentation and microbial protein availability. Together these studies highlight the greater importance of protein for wool growth than energy.

The weight and diameter of wool produced by sheep is influenced by the ratio of primary to secondary wool follicles (Thompson et al. 2011b). The number of primary follicles is genetically determined (Jackson et al. 1975; Hocking Edwards et al. 1994) and the development of the follicle population in the foetus is influenced by maternal nutrition (Short 1955; Schinckel and Short 1961; Everitt 1967). Fibre diameter is considered to be the most important property of wool for processing (Lipson, 1972) and varies within a staple, along a fibre, location of growth on an animal and between animals (Teasdale, 1998). Changes in fibre diameter within a staple are primarily a result of variability of secondary follicles that are sensitive to changes in nutrition (Lyne 1964) and are considered to be a more subtle indicator of changes in an animal’s diet than live weight or BCS. Fibre diameter and the coefficient of variation of fibre diameter (CVFD) are major determinants of staple strength. A large fibre diameter is associated with a higher staple strength and a low coefficient of variation in fibre diameter within a staple also provides a higher staple strength. However, variation in diameter along the staple also influences staple strength where high variability will result in a weaker staple (Reis 1992).

The length, strength and diameter of wool fibres are influenced by gender (Magolski et al. 2011), live weight (Sharkey et al. 1962; Allden 1979; Masters et al. 1998), the location of fibre growth on the body (Sharkey et al. 1962), physiological state (Reid 1978; Sumner and Bigham 1993) as well as seasonal environmental effects of day length (Ferguson et al. 1949) and temperature (Coop and Hart 1953). In general a consistent high quality diet is associated with greater wool growth, staple strength and length and lower variation in fibre diameter along a fibre. Variations in wool growth and fibre diameter are associated with seasonal rainfall and the strong influence of rainfall on forage green leaf availability and quality (Freudenberger et al. 1999). As a
result of the positive associations of diet quality and intake and animal production parameters, management strategies should aim to manage animals and pastures with these objectives in mind.

2.6 Management effects on the diet and production of sheep

A large proportion of land within the HRZ of the Central Tablelands of NSW and south-eastern Australia is dedicated to livestock production within heterogeneous landscapes and complex native pastures. Producers and managers face the challenge of balancing sustainability parameters (natural resource outcomes) with desirable pasture compositions, as well as pasture availability and utilisation with profitable animal production within variable climates. In terms of the overall performance of a system SR is considered to be a significant factor in animal production and the most important factor determining productivity, sustainability and composition of vegetation (Hart et al. 1993b; Hickman et al. 2004). An inappropriate SR can result in detrimental effects on pastures and landscapes and over- or under-utilisation of the forage. An important consideration is the grazing management strategy or system that is implemented.

2.6.1 Stocking rate

Stocking rate is the number of animals per area unit of land at a specific point in time and may be described as the area of land allocated to an individual animal. The SR when averaged over a year or grazing season is known as the stocking density of a paddock or system. The SR of a production enterprise is an important management decision affecting the profitability, productivity and sustainability of a system. A correct SR will provide forage of sufficient quantity and quality to optimise animal production whilst sustaining the pasture and resource base (Garcia et al. 2003). Stocking rates may be fixed or flexible and, according to Wilson and Hodgkinson (1991), SR is considered to be the most important management ‘tool’. The set-stocking of animals throughout the year will usually result in pastures being understocked during the main green feed growth period and over stocked during the dry and or non-growing feed period (Morley 1981; Vizard and Foot 1994). In contrast, Holst et al. (2006) found animal production can be maximised regardless of pasture type provided SR was flexible and matched to feed availability. Stocking rates may be adjusted to match changes in animal requirements associated with pregnancy and lactation as well as seasonal changes in feed availability that typically occur within the region prior to or during spring when
green feed is typically abundant and over the autumn winter period with reduced pasture growth.

High SR is associated with a reduction in individual animal live weight, reproduction, wool production and lamb growth rate (Lloyd-Davies and Southey 2001). On the other hand, high SR can increase production per unit of land area and thus profit (Jones and Sandland 1974; White et al. 1980; Holmes Sackett 2011). However, excessive SR together with drought and selective grazing have resulted in extensive environmental and pasture degradation (Asner et al. 2004) including soil erosion, acidification and salinity (Kemp et al. 2000; Dorrough et al. 2004a; 2004b) and pasture condition (Bryant et al. 1989) as well as a decline in perennial pastures species (Kemp et al. 2000; Dorrough et al. 2004a; 2004b), palatable plant vigour and recruitment (Leigh and Holgate 1978; Freudenberger et al. 1999) and increased variability of forage supply (Kemp et al. 2000). The frequency and severity of defoliation of plants increases as SR increases (Briske and Stuth 1982). Curll and Wilkins (1982) found the quality of pasture grazed by sheep at higher SR was greater, but lower in quantity than at low SR. The grazing of animals at low or inadequate SR over extended periods of time can lead to large areas that are under utilised or neglected and the overgrazing of preferred areas and plants and the resulting loss of preferred plant species and a decline in pasture quality (Mott 1987; Fuls 1992; Norton 1998). To minimise damage to vegetation and soil moderate SR are recommended (Ralphs et al. 1990). However, managing the SR of grazing animals is one of a number of management interventions.

2.6.2 Grazing management systems

Grazing systems are broadly described as specific time schedules of animal species and densities for two (deferred-RG) or more pastures in which the grazing, post-grazing residual vegetation and regrowth (or rest) interval of plants are regulated by reoccurring phases of grazing, rest and deferment (Heitschmidt and Taylor 1991; Saul and Chapman 2002). Grazing systems are implemented in contrast to CG or zero management (Beattie 1994) where animals are restricted to a single paddock throughout the year and plants are continuously exposed to grazing. The duration of grazing and rest is determined by the number of paddocks within a system (or rotation) together with the growth rate of the pasture and the food-on-offer (FOO). The underlying rationale of grazing systems is that smaller paddock sizes improve spatial efficiency and forage utilisation is increased. At high stocking densities livestock selectivity is substantially reduced and the relative
grazing pressure on preferred plant species as the defoliation of less preferred species is simultaneously increased (Norton 1998). Producers and managers are able to modify the intensity and location of animal grazing by altering the frequency, duration and timing of grazing and rest as well as species of animal, SR, stocking density and herbage allowance (Scarnecchia and Kothmann 1982; Kemp et al. 1996; Dowling et al. 2006).

Research of the effect of grazing systems on pastoral ecosystems has reported highly variable results in terms of pasture composition as well as plant and animal production. The results are complicated by a plethora of confounding factors that include variability of management practices, landscapes and grazing environments, species of animal, climatic conditions, study duration, study methodologies and whether treatments were replicated.

Within Australia few studies to date have investigated the effect of high intensity RG systems. A study by Warn et al. (2002) found the carrying capacity of an improved pasture could be increased (by 17 to 21%) in an intensive plant-based rotation under high and low application of P fertiliser without compromising individual animal production in comparison to CG. Within a fixed time-based rotation a 10% increase in SR in comparison to CG was observed under the high application of P fertiliser treatment. No differences were recorded in wool production and wool quality between the systems. The authors concluded that the movement and management of animals within grazing systems should be flexible and based on plant-growth rather than a rigid time-basis. In an unreplicated study, Dowling et al. (2005) observed significant pasture compositional changes after 18 months with an increase in preferred palatable perennial species and a decline in undesirable pasture species under a high intensity tactical RG system. However, the effect was transient as there were no differences in pasture production between the two management systems after six years. In a large replicated grazing experiment, Dowling et al. (2006) found changes in native swards between a flexible, tactically grazed system and CG. Plant species composition deteriorated under CG and remained so, especially where fertiliser was applied and resulted in a weed dominated sward. In comparison the proportion of desirable plant species increased under the flexible, tactical RG system, where the long-term SR was ~10% lower. As both treatments were conservatively stocked, there were minimal differences in individual animal live weight or wool production between the grazing systems (Holst et al. 2006) as the sheep could still exercise some selectively.
Studies of low-intensity rotational grazing systems of sheep grazing native pastures within Australia have reported greater forage production under a fixed RG system but no differences in individual animal live weight (Lodge et al. 2003a; 2003c). Studies within improved pastures have reported increased forage production and available herbage mass under RG in comparison to CG (Lloyd Davies and Southey 2001; Chapman et al. 2003), although animal live weight was comparable under a deferred rotation (Lloyd Davies and Southey 2001) and a fixed and variable rotation (Chapman et al. 2003). Similarly, Morley et al. (1969) reported comparable animal production between continuous and tactical rotation grazing management systems and an inconsistent effect on forage production, although there were significant shifts in plant species composition which in the longer-term could affect animal production. In contrast, Waller et al. (2001) recorded a higher live weight of RG ewes, in comparison to ewes managed within a CG system, where plant species composition changes occurred early in that study.

Inconsistent effects of grazing systems on animal production and plant species composition have been observed in international studies in sheep and cattle. Little to no difference was recorded in the vegetation between rotational and CG under a flexible RG system (Gutman and Seligman 1979; Gutman et al. 1990) or short-duration grazing system (Bertelsen et al. 1993; Hart et al. 1993a; 1993b) nor in animal production between the grazing systems (Gutman and Seligman 1979; Bertelsen et al. 1993; Hart et al. 1993a; 1993b). In a fixed RG grazing system (Sharrow and Krueger 1979; Sharrow 1983) and a short duration grazing system (Walton et al. 1981) greater forage production was observed as well as trends in greater live weight gain (Sharrow and Krueger 1979; Walton et al. 1981) in comparison to a CG system. Heitschmidt et al. (1982a; 1982b) observed similar trends of greater live weight gain in a short-duration grazing system compared with a CG system. Many studies have often shown plant species composition shifts under different grazing systems, but these effects were occurring towards the end of the study and there is a need for long-term studies to determine the full impact of these species shifts on livestock production as well as the sustainability of the grassland (Kemp and Dowling 2000). Other work has shown that most common pasture species are affected by grazing practices, though this impact varies with species and season and thus necessitates flexible grazing practices rather than rigid RG systems (Kemp et al. 2000).
Increased pasture production and carry capacities have been reported for pasture-based dairy systems in New Zealand under rotational and restrictive grazing management systems (de Klein 2001). However, a review of the relevant literature indicates the majority of grazing system studies have failed to demonstrate a clear benefit of implementing grazing systems in terms of individual animal production and vegetation composition. This is in contrast to the reports presented by Norton (1998) of producers in Australia, South Africa and North America that claim improved species composition, land productivity and an increase in SR. On farm multi-paddock systems are routinely used in some form, suggesting that farmers perceive real benefits. The limited research support for RG systems providing benefits for animal production may reflect the constraints in much research where grazing densities and intensities are lower and rotation patterns may not be as flexible as applied on farms and treatment effects may only be starting to emerge at the time experiments conclude. The benefits of a grazing system can be judged in terms of effects on animal production, vegetation or some other parameters including increased stocking rates. However, much of the literature has focused solely on animal production and few studies to date have investigated the effect of grazing management systems on the quality of the diet selected by animals. In order to gain greater understanding of the impact of grazing systems on vegetation composition and animal production in particular the impact of variations in diet quality over time further research is essential. Further research is crucial to provide objective information to producers to monitor and enhance livestock production within heterogeneous landscapes and grazing systems.

2.6.3 Management tools
The ‘tools’ of grazing systems available to producers include; altering the species of animal, SR, stocking density, herbage allowance, as well as the frequency, timing and duration of grazing and rest (Scarnecchia and Kothmann 1982; Kemp et al. 1996; Dowling et al. 2006). Management tools must be simple, relatively non-invasive, low cost, effective and easy to apply within variable landscapes and to large numbers of animals. A greater understanding of animal behaviour, diet selection and landscape use of sheep grazing within heterogeneous landscapes and native pastures is essential to the development and refinement of objective management ‘tools’ for producers to enhance animal and ecosystem productivity. It may be that within the normal course of a short-
term study effects on animal production could be minimal, but the trends established could lead to significant impacts in the medium to long-term.

2.7 Conclusion
Sheep grazing within heterogeneous landscapes and pastures need to satisfy their nutrient requirements. The effect of landscape variability and vegetation diversity on animal grazing behaviour and performance are not well understood nor is the affect of grazing systems on the performance and diet selectivity of grazing sheep. Producers and managers face the complex challenge of improved animal performance whilst maintaining desirable pasture composition, positive natural resource outcomes as well as pasture availability and utilisation. The challenge is further complicated by limited objective information and reliance upon low to no cost ‘tools’ to gain a greater understanding of how animals are grazing within these complex landscapes and grazing systems. What grazing animals eat and why they are choosing what they do in complex pastures is still one of the least understood aspects of animal nutrition.
Chapter 3. Materials and Methods

Common protocols and procedures were used for the series of experiments reported in this thesis. Presented in this chapter are the basic details on the experiment site, the experiment designs and common protocols and procedures used.

3.1 Experiment location and management

The studies reported in Chapters 4 to 8 including the: animal studies (Chapter 4 and 7), small plot grazing experiments (Chapters 5 and 6), GPS monitoring (Chapter 8) and plant and faecal collections (Chapters 4 to 7) occurred at the Central Tablelands EverGraze Proof Site, at Panuara in NSW. The landscape description of the 40 ha native pasture site was conducted in late 2007 and the site was established in 2008. This study was conducted from October 2009 to December 2011. The use and care of animals was approved by the Charles Sturt University Animal Care and Ethics Committee (protocol number: 09/107) and the management of the animals at the site was also approved by NSW Department of Primary Industries (NSW DPI) Animal Authority (protocol number: 07/005).

The small plot grazing experiments reported in Chapters 5 and 6 were conducted at the site outside of the established experiment in four small plots located in the overflow area at the site. The experiments reported in Chapters 4, 7 and 8 were conducted within the established EverGraze experiment designed to evaluate contrasting grazing management systems. Within the following sections experimental design (3.1.4), animal study (3.2) and plant study (3.3) the materials and methods of the small plot experiments are firstly outlined and the details of the larger grazing system study are subsequently described.

3.1.1 Climate

The site was located within the HRZ of south-eastern Australia with an average annual rainfall of 833 mm at the site. The long-term average monthly rainfall and maximum and minimum temperatures are summarised in Figure 3.1. Summer temperatures are mild to warm with maximum daily temperatures exceeding 20°C for 6 months at the site. Winter temperatures within the region are cool and frosts can occur for 5-7 months of the year. Rainfall is distributed throughout the year and in summer evaporation exceeds rainfall and pasture growth is limited by moisture availability whereas during
winter pasture growth is typically limited by temperature as rainfall exceeds evaporation.

3.1.1.1. Climatic data
Meteorological data was collected at the site from September 2007 onwards. Rainfall (total and intensity), temperature, solar radiation, relative humidity, and wind speed were recorded on an automatic weather station at 15 minute intervals.

Figure 3.1. Long-term average monthly rainfall (columns) and maximum (green) and minimum (blue) temperatures (1912–2007) at the study site. (Source: Datadrill)

3.1.2 Geology, landscape and soil
The landscape of the site is highly variable with an average elevation of 795 m (range: 770-820 m) and soils of varying depth and fertility. The soils are derived from siltstone and are brown chromosols and kurosols (Isbell 1996). Prior to the commencement of the experiment the site was mapped into three production zones: high, medium and low (Figure 3.2), to describe this variability. High production zones (HPZ) predominated the lower slopes, medium production zones (MPZ) were located on the mid-slopes and low production zones (LPZ) dominated the upper slopes (Badgery, unpub. data).

The production zones accounted for differences in pasture production and composition and soil properties. There were significant differences in soil phosphorus (P) (Bray test, Rayment and Higginson (1992) test 9E2), pH levels and herbage mass between zones (Badgery et al. 2011) (Table 3.1).
Figure 3.2. Map of study site (Badgery, unpub. data) Replicate 1 (blue outline); Replicate 2 (green); Replicate 3 (red); Small plots (black). The subplots within the three rotational grazing treatments (refer to section 3.2.2) are shown in bold. Blue circles denote areas of shade and/or shelter within the studied areas.

Table 3.1. The total area, average soil P (Bray test) and pH and pasture herbage mass of the low, medium and high production zones at the study site (Badgery et al. 2011).

<table>
<thead>
<tr>
<th>Production zone</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (ha)</td>
<td>8.3</td>
<td>23.2</td>
<td>8.0</td>
</tr>
<tr>
<td>Soil P (mg/kg)</td>
<td>40.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.5&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Soil pH</td>
<td>4.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.7&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pasture herbage mass (DM kg/ha)</td>
<td>905&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1151&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1429&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a-c</sup> values in the same row with different superscripts are significantly different (p < 0.001)

3.1.3 General vegetation
The native pasture (with a history of superphosphate fertiliser application and the over-sowing of T. subterraneum) at the site is typical of much of the region. The pasture is dominated by native perennial pasture species and includes C3 grasses (Austrodanthonia spp., Austrostipa spp., Elymus scaber and Microlaena stipoides), C4
grass (*Bothriochloa macra*), introduced C3 grasses: *Holcus lanatus, Lolium rigidum, Poa bulbosa*, legumes: *T. subterraneum*, forbs: *Acetosella vulgaris* and *Hypochaeris radicata* and other monocotyledons: *Juncus* spp. and *Asphodelus fistulosus*. The location of the species in the landscape is typically associated with identified production zones as outlined in Table 3.2.

### 3.1.4 Experimental design

The EverGraze experiment was designed to evaluate low-intensity, medium-intensity and high-intensity grazing systems in a randomised-block design. The production zones at the site were used to determine the location of the grazing treatment blocks to ensure all plots within a replicate block had a similar productivity potential (Badgerly, unpub. data). Each treatment plot was 3.5 ha in size and there were three replicate blocks.

The grazing treatments were:

- **Low intensity** (CG) – 1-paddock CG continuously grazed.
- **Medium intensity** – 4-paddock rotation: the grazing area was divided into four paddocks and animals were rotated within the paddocks. The animals were moved into the most suitable paddock according to the available feed, animal requirements and stage of pasture growth. The paddocks were not grazed in a fixed sequence.
- **High intensity** (RG) – 20-paddock rotationally grazed system: the grazing area was separated into 20 paddocks with the length of grazing of each paddock determined by the total available feed. Similar to the 4-paddock rotation the paddocks were not grazed in a fixed sequence, animals were moved based on the: available feed, animal requirements and the stage and rate of pasture growth. This flexibility was included in the design to reflect farmer management practices, and a farmer steering committee helped set the guidelines for management. The average length of grazing was four days with an average rest period of 70 days (range = 1 - 7 days of grazing and 30 - 140 days of rest).

For this thesis only the CG and RG treatments were used.

### 3.1.4.1 Small plot location

Four replicate plots (0.08 ha; 20 m x 40 m) were established in 2009 within the overflow area between replicates 1 and 3 for more detailed studies (Figure 3.2) reported
in Chapters 5 and 6. The plots were paired, based on available forage and similar botanical compositions (plots 1 and 3, and 2 and 4, respectively were paired).

**Table 3.2.** Dominant pasture species of the low, medium and high production zones at the study site.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasses (native – C3)</td>
<td><em>Austrodanthonia</em> spp.</td>
<td><em>Austrodanthonia</em> spp.</td>
<td><em>Microlaena stipoides</em></td>
</tr>
<tr>
<td></td>
<td><em>Austrostipa</em> spp.</td>
<td><em>Elymus scaber</em></td>
<td></td>
</tr>
<tr>
<td>Grasses (native – C4)</td>
<td><em>Bothriochloa</em> spp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grasses (introduced – C3)</td>
<td><em>Poa bulbosa</em></td>
<td><em>Lolium rigidum</em></td>
<td><em>Holcus lanatus</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Poa bulbosa</em></td>
<td><em>Lolium rigidum</em></td>
</tr>
<tr>
<td>Legumes (introduced)</td>
<td></td>
<td></td>
<td><em>Trifolium subteraneum</em></td>
</tr>
<tr>
<td>Other monocotyledons</td>
<td></td>
<td></td>
<td>Juncus spp.</td>
</tr>
<tr>
<td>(introduced)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td><em>Acetosella vulgaris</em></td>
<td><em>Hypochaeris radicata</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Hypochaeris radicata</em></td>
<td></td>
</tr>
</tbody>
</table>

**3.1.4.2 Site management and monitoring**

Soil moisture within each treatment replicate was assessed at five to six neutron probe measurement tubes that were periodically sampled at six to eight week intervals. Soil chemical, physical and biological fertility were assessed annually (within a 10 m radius of the neutron probe measurement tubes) at the site.

Single superphosphate fertiliser (8.8 % P, 11 % S) was strategically applied to areas that would most likely respond to additional nutrients. The identified areas were the HPZ within each treatment replicate. Fertiliser was applied at a rate of 250 kg/ha and 125 kg/ha in April 2009 and April 2010, respectively.

The site was grazed by high performance Merino ewes (CentrePlus®), which were born in spring 2005 and then later mated to terminal sires (white Suffolk rams). This reflects current practice in the region. The hybrid lambs have a higher growth potential than a pure-bred Merino and are used for meat production. At the commencement of the experiment all animals were randomly allocated to the treatment groups and replicates.

Ewes were crutched in March prior to joining for four weeks commencing in late March or early April. Shearing occurred in May and the ewes were pregnancy scanned in June. Each treatment replicate was ‘balanced’ for single and multiple conceptus number following scanning in June after which SR adjustments were made to achieve the same
potential number of lambs per ewe in each group. Lambing occurred in August and September, to coincide with the beginning of the period of highest pasture growth.

Lambs were weaned and sold from mid November to late January depending upon feed availability and live weight. The removal of lambs was based on FOO, herbage mass and whether lambs reached a target weight (42 kg) or average growth rate fell below less than 100 g/hd/d.

For the first 12 months of the experiment (and prior to the research reported in this thesis) all treatments had the same SR (5.4 ewes/ha) after which the SR was adjusted for individual plots to achieve similar levels of FOO within each plot and adjust to seasonal pasture production predictions together with the animals’ nutrient requirements. Minimum FOO targets for different stages of animal production formed the basis of SR decisions to ensure animal requirements were met. These targets were based on Prograze (Noad 2003) and are shown in Table 3.3.

The annual SR decision occurred between the weaning of lambs and the joining of ewes each year (December to March) and at scanning (June). If FOO was insufficient to meet the animals’ requirements, the ewes were removed from the plots and fed for a period of time, which only occurred in June and July (2009).

**Table 3.3.** Minimum food on offer (FOO) (kg DM/ha) targets – Prograze™ (Noad 2003).

<table>
<thead>
<tr>
<th>Sheep class</th>
<th>Pasture digestibility (stage of plant growth)</th>
<th>75% (actively growing)</th>
<th>68% (mid flowering)</th>
<th>60% (fully mature and drying)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry ewes</td>
<td></td>
<td>400</td>
<td>600</td>
<td>1200</td>
</tr>
<tr>
<td>Pregnant ewes</td>
<td></td>
<td>500 – 700</td>
<td>700 – 1200</td>
<td>1700</td>
</tr>
<tr>
<td>Lactating ewes – single</td>
<td></td>
<td>1000</td>
<td>1700</td>
<td>-</td>
</tr>
<tr>
<td>– twin</td>
<td></td>
<td>1500</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lambs growing</td>
<td></td>
<td>90%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(percentage of potential)</td>
<td></td>
<td>50%</td>
<td>2200</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>800</td>
<td>1600</td>
</tr>
</tbody>
</table>

Where cells are blank (-) the pasture quality will not support the animal class.

All animals at the site were weighed every four weeks using a crate mounted on the same portable electronic sheep scales; their BCS (Jefferies 1961) was assessed at the same time. The BCS of the animals was assessed using a scale of 1 to 5, with 5
indicating the fattest. To minimise operator variation, as far as possible the same person conducted the BCS assessment each time.

The vegetation biomass and composition was assessed using BOTANAL procedures (t’Mannetje and Haydock 1963; Jones and Hargreaves 1979; Tothill et al. 1992) at 60 permanent points within each replicate every four to eight weeks. The pre- and post-grazing biomass of six paddocks within each replicate of the 20-paddock (RG) system was assessed at 23 points along two transects and the permanent points within each paddock.

3.2 Animal measurements

This study involved both small grazing plot studies (reported in Chapters 5 and 6) and the study of animals grazing within the contrasting grazing systems (CG and RG), presented in Chapter 4, 7 and 8.

3.2.1 Small plot studies

A total of 20 dry and not pregnant ewes (3.5 years of age) were randomly selected from a flock of sheep grazing at the site and thus were familiar with the pasture. The sheep were weighed and their BCS assessed prior to the study commencement, the period of wool growth (months) recorded and 10 sheep were randomly allocated to each group.

3.2.2 Grazing management system studies

The Merino ewes managed at the site within the CG and RG system treatments were weighed and their BCS assessed prior to and following each grazing period and were managed according to the site management practices (see section 3.1.4.2). The composition and quality of the diet selected by ewes was monitored within a single paddock of a 20-paddock RG treatment. The experimental paddock was located within a MPZ at the site. Simultaneously, the composition and quality of the diet selected by ewes managed within the CG system at the site was monitored. Within the RG and CG systems the three replicates were grazed successively. During each replicate study GPS collars were fitted to the animals, as outlined in section 3.4.

3.2.2.1 Faecal collections

Three fresh faecal samples were collected from pasture at the same time each day from each treatment (0900 h from the RG treatment and 1000 h from the CG treatment). Each sample comprised five faecal samples, which were placed in labelled bags and placed in
a cooled, portable icebox prior to drying. Samples were collected from both treatments for the duration of the grazing of the RG paddocks and then four subsequent days (after the completion of grazing) to account for the rate of passage of digesta of approximately 60 to 72 h (refer to Appendix A for a detailed description of the estimation of the passage rate of digesta). On the day of collection the faecal samples were oven-dried at 60°C for 48 h then ground through a 1 mm screen using a hammer mill (Humboldt Mfg Co. IL, USA) before chemical analysis.

3.2.2.2. Wool dye-banding
Dye-banding of all of the sheep at the site was conducted three times (October 2009; December 2009 and March 2010) and at the same time as live weight and BCS assessments were conducted.

The animals were placed in a cradle, the right mid-side of each animal was parted into a vertical line and a narrow band of dye (silver nitrate and hydrogen peroxide solution) was applied to a minimum length of 100 mm at the skin level of the parted wool (Chapman and Wheeler 1963; Williams and Chapman 1966) using a pipette. Dye-banded mid-side samples of all animals were removed a day prior to shearing in May 2010. Mid-side samples (non dye-banded) were also removed a day prior to shearing in May 2011. Hand-held animal clippers (Oster® Golden single speed) that cut the samples to skin level were used. Wool samples that were sent for analysis were from ewes that were managed within the grazing systems at the site for the majority of the year (greater than 10 months).

3.2.2.3 Fleece weight and wool growth
The fleece weight (skirted fleece that included belly) of each ewe was recorded at shearing (May of each year). Average monthly wool growth was calculated and used to adjust the average live weight of the ewes over time to eliminate wool growth effects from the live weight data.

3.3 Plant measurements
3.3.1 Small plot studies
The pasture biomass and composition was assessed using a 0.25 m² (0.5 m x 0.5 m) quadrat in a regular grid formation (4 m x 4 m) prior to and following grazing at 36 permanent points established within each plot.
3.3.1.1 Pasture biomass, phenology and species selection

The total, green, dead and litter biomass (kg DM/ha) and ground cover (%) were estimated by direct visual assessment (Campbell and Arnold 1973). The botanical composition of each quadrat was estimated by direct visual assessment of the green and dead biomass (kg DM/ha) of all species present. The estimated values were corrected using the estimated and actual values from calibration quadrats that were sorted into dead and green components. Prior to the commencement of each grazing period 10 calibration quadrats from the area surrounding the grazing plots were firstly estimated then cut, dried and sorted into the green and dead components of each species to determine actual values. Regression analysis was conducted and $R^2$ values of 0.9 or greater were achieved and considered acceptable (Campbell and Arnold 1973). The developmental stage of each species was recorded at the initial pasture assessment (prior to grazing) as either; vegetative (V), reproductive (R) and senescent (Sc). Vegetative referred to green, actively growing plants prior to flowering, with minimal stem development. Reproductive included plants in flowering and fruit development stage, with more stem growth. Senescent referred to plants with dry stems, leaves, seeds and seed pods.

During each grazing period the pasture was assessed daily and a grazing rating assigned to the green and dead components of each species according to the grazing rating summarised in Figure 3.3 (refer to Appendix B for a detailed description of the development of the grazing rating index). The index identified the plant species consumed by the animals and the extent to which each species within a quadrat was grazed. At each pasture assessment of every quadrat in all studies a photograph was taken (in which the quadrat was clearly labelled) for later verification.

![Grazing rating index to identify plant species and parts removed by grazing animals.](image)

**Figure 3.3.** Grazing rating index to identify plant species and parts removed by grazing animals.
3.3.1.2 Estimated diet composition
The average daily composition of the diet of each group of ewes was estimated from the pre- and post-grazing biomass together with the daily grazing rating data. The contribution of each plant species to the daily intake of the animals within each plot was then calculated as a proportion (%) of the diet consumed each day.

3.3.1.3. Evaluation of the nutritive value of plant species components
Plant material of the major pasture species was hand-plucked from the plot area prior to grazing and additional samples were collected following daily identification of the pasture species consumed by the animals. Similar quantities of each species were harvested to fill standard collection bags. Average green biomass samples of the pasture were comprised of sub-samples of the harvested and hand-sorted calibration quadrats. All samples were oven-dried (60°C for 72 h), hand sorted and ground using a hammer mill (1 mm screen) and sent for chemical analysis.

3.3.2 Grazing management system studies
The pasture biomass and composition of RG treatment paddock replicates were assessed prior to and following grazing at 60 permanent points in a regular grid across each paddock. Within the CG treatment pasture biomass and composition was assessed within two areas identified as high utilisation (HU), where animals spent the highest proportion of their time grazing and low utilisation (LU), where animals spend the least amount of time grazing during the initial day of monitoring (refer to section 3.4.2 for further details of the observation of animal location). Within each area the pasture was assessed at 20 locations (10 m intervals) along two 90 m transects. For both treatments the pasture biomass and composition was assessed using a 0.25 m² (0.5 m x 0.5 m) quadrat.

3.3.2.1 Pasture biomass and phenology
The pasture biomass and phenology of the RG and CG treatments were estimated using the same techniques outlined in section 3.3.1.1.

3.3.2.2 Plant species selection
During grazing the pasture within the RG paddocks was assessed daily using the grazing rating index outlined in section 3.1.1.1 and Figure 3.3.
Within the CG paddocks the grazing rating (Figure 3.3) was used to identify the plant species consumed by the animals within the CG treatment. The extent to which a plant had been grazed was estimated based upon the surrounding vegetation, where there was no visual sign of grazing.

### 3.3.2.3 Estimated diet composition

The average daily composition of the diet of the animals managed within the RG treatment was estimated using the same technique outlined in section 3.3.1.2. The plant species selected by the animals managed within the CG treatment was identified by the grazing rating index and as it was not possible to estimate the specific intake of each animal, the data reflects group behaviour.

### 3.3.1.4 Evaluation of the nutritive value of plant species components

Plant material of the major pasture species and of the species identified as being consumed by the animals, was hand-plucked from the RG paddock prior to grazing. Additional samples were collected following daily identification of the pasture species consumed by the animals. Samples were collected from the CG treatment at the same time as the pasture biomass and composition was assessed within the area of HU. Average green biomass samples of the pasture within the RG paddock and the two areas monitored within the CG treatment, were taken and comprised sub-samples of the harvested and hand-sorted calibration quadrats. All samples were oven-dried (60°C for 72 h), hand sorted and ground using a hammer mill (1 mm screen) before being sent for chemical analysis.

### 3.4 GPS monitoring

GPS collars were fitted to a number of animals during the study of animals managed within the contrasting grazing systems (CG and RG) at the site. During each (replicate) study eight GPS collars were fitted to four randomly selected ewes within each of the RG and CG treatments.

#### 3.4.1 GPS tracking and grazing activity

GPS collars (Bluesky Telemetry Ltd, Scotland) were fitted to the ewes and all collars were programmed to record data every 15 s starting at 00:00 h prior to the RG ewes entering an intensively monitored paddock and programmed to stop 4 days later at 00:00 h after the RG ewes were moved to another paddock after 2 days of grazing. Each record included the date, time, latitude, longitude, temperature, satellite number and
motion sensors within the collars recorded the location of the animal’s head as four tilt values (maximum roll tilt, minimum roll tilt, maximum pitch tilt, and minimum pitch tilt).

### 3.4.2 Observation of animal location
The location and activity of the animals within each grazing treatment was recorded every 20 minutes by the same observer for the duration of the first day (0600 h to 1800 h). Observation data was used to verify recorded GPS locations, animal activity and identify areas of high- and low-utilisation by the animals within the CG paddocks.

### 3.4.3 Data processing
GPS positions were plotted using ArcMap™ (ESRI, Australia) and overlaid with the three production zones (high, medium and low) within each paddock; the production zone each record was located in was identified. Using the difference between the maximum and minimum pitch values (Umstätter et al. 2008) the behavioural activity of each animal for every record was determined as either active (grazing, graze walking, walking with head down) or inactive (standing with head up, lying or sitting with head up, walking with head up).

### 3.5 Analytical procedures

#### 3.5.1 Wool analysis
Dye-banded (2010) and non-dye banded (2011) mid-side wool samples were analysed at the Australian Wool Testing Authority in North Melbourne, Victoria. The analysis included wool staple profiles, length and strength testing and wool yield measurements.

##### 3.5.1.1 Wool fibre profiles
Samples of approximately 10 000 to 20 000 fibres were washed with petroleum ether and left to dry and stabilise in a climate controlled room at 20°C and 65% relative humidity for 24 h. Each sample was then spread on a fibreglass slide and scanned with an OFDA2000 (Baxter 2000) that automatically profiled the wool fibres and the average fibre diameter and distribution were recorded.

##### 3.5.1.2 Length and strength testing
The total staple length, staple strength and position of break (based upon on the diameter profile) from each mid-side sample collected were measured with an automatic tester of length and strength (ATLAS).
3.5.1.3 Wool yield measurements
To determine the proportions of growth between dye-bands staples from individual ewes were weighed (to three significant figures) and then cut at the base of each dye-band. Each section was then weighed, washed in (individual) bags in a soxlet alcohol extraction unit and syphoned for between 2 to 3 h (approximately 40 syphons in total). The bags were removed from the extraction chamber and oven-dried for 18 h to remove excess alcohol. Samples were cooled in a climate controlled room for approximately 2 h. The clean and dry sample was then removed from the bag and weighed to determine clean fleece yield (%).

3.5.2 Plant and faecal analysis
Analyses of the vegetation samples included N and ash contents, DMD, digestible organic matter within the dry matter (DOMD) and ME. The analysis of faecal matter included $fN$, faecal neutral detergent fibre ($f$NDF), faecal acid detergent lignin ($f$ADL) and faecal ash ($f$Ash).

N (and $fN$) content was determined using the Dumas combustion method with a Leco CNS 2000® analyser (Leco, St. Joseph, MI, USA) (AOAC 1990b). NDF and ADL (and $f$NDF and $f$ADL) were analysed sequentially (van Soest et al. 1991) using the filter bag method (Ankom® 200/220 fibre analyser, ANKOM technology, Macedon, NY, USA). Ash (and $f$Ash) was determined by combusting the sample in a muffle furnace for 6 h at 550°C (AOAC 1990a; AFIA 2006a).

The DMD and DOMD of the pasture samples was analysed using the pepsin cellulase digestibility assay (Clarke et al. 1982; AFIA 2006b) and a modified Tilley and Terry (1963) two-stage digestibility assay. The modification to the Tilley and Terry method involved adding urea (0.156 g/L) and ammonium sulphate (0.156 g/L) to the buffer solution to provide an additional source of N to compensate for the low N status of some feed samples.

3.6 Calculations
3.6.1 Metabolisable energy of pasture
The ME value of each pasture sample was estimated using the following empirical formula (NSW Agriculture 1983) which was based on a very large database:
OME (MJ/kg DM) = 0.17 DDM% - 2.0

(where DDM% = 83.58 – 0.824 ADL% + 2.626 N %)

3.6.2 Faecal chemistry predictive equations
The animal’s dietary OMD and ME (MJ/kg DM) were estimated using equations derived by Mahipala et al. (2009) and dietary OMD was also estimated by an equation developed by Wang et al. (2009). The following equations derived by Mahipala et al. were from oaten hay (*Avena sativa*) and browse-containing diets that included *Acacia saligna*, *Chamaecytisus palmensis* and *Atriplex amnicola*:

OMDₘ (g/kg DM) = 814.55657 - 514.4869 (fADL /fNDF) - 0.93196 (fAsh) - 5.4971 (fN)

Diet MEₘ (MJ/kg DM) = 12.32323 - 8.25181 (fADL /fNDF) - 0.01522 (fAsh) - 0.07933 (fN)

The predictive model developed by Wang et al. incorporated forages from Germany and Inner Mongolia (China) that included; fresh grass, grass silage, alfalfa silage, soybean concentrate and *Leymus chinensis*, *Stipa grandis* (common C3 grasses of the Eurasian steppe) and *Artemisia frigida* (common forb). Diet OMD was calculated using the following formula:

\[ \text{OMD}_W = 0.899 - 0.644 \times \exp \left( -0.5774 \times \text{faecal CP (g/kg OM)/100} \right) \]

3.7 Statistical analysis
Treatment means and standard error of the mean (SE) for all parameters were analysed using analysis of variance (ANOVA) (Genstat® 13th edn, Hemel Hempstead United Kingdom) and differences were significant when p < 0.05.

Comparative analysis of faecal chemistry predictive equations (Chapter 5, 7, 9 and 10) was completed using regression analysis. Relationships between the percentage of herbage consumed and the initial green to dead ratio and pasture DOMD of pasture species (Chapters 5, 6 and 7) were analysed using regression analysis.

Residual maximum likelihood (REML) analysis was used in Chapter 4 and principal component analysis (PCA) was used in Chapter 8.
Chapter 4. Sheep Production

4.1 Introduction

The interactions between grazing herbivores and plants are inherently complex and management decisions can have a profound influence on plant-animal interactions. Grazing management systems seek to control the relationship between animals, plants and soil by regulating the number of animals and the duration and location of grazing animals, which affects an animal’s selectivity and distribution within an ecosystem (Beattie 1994). Studies comparing continuous and rotational grazing have demonstrated the complexity of plant-animal interactions (Jensen et al. 1990) with variable results and benefits recorded within different landscapes and pastures and between producers and researchers. Knowledge of the nutrition and diet selection of sheep grazing within native pastures and grasslands and the influence of grazing management systems is limited. A greater understanding of the plant-animal interactions and the influence of management decisions, in particular grazing management systems, is essential for the development of more efficient animal production systems.

There are two main forms of grazing management, continuous and rotational. Continuous grazing or ‘zero management’ (Beattie 1994) involves restricting a herd or flock to a single paddock throughout the year and plants are continuously exposed to grazing by livestock. Depending on the SR, animals may be able to select a highly nutritious diet but preferred plants may experience heavy, selective and destructive utilisation that results in a decline in palatable plant vigour and recruitment (Leigh and Holgate 1978) whilst less preferred plants have a competitive advantage and increase at the expense of more preferred plants (Sharrow and Krueger 1979). Livestock grazing is typically ‘patchy’ or unevenly distributed within the landscape and results in the over-utilisation of some areas and the establishment of grazing patches and the under utilisation of other areas. The heavy utilisation of areas within a paddock means the ‘effective’ SR in some parts of the paddock is much higher than the intended SR (Suckling 1965). Grazing pressure can be modified by changes in SR to control grazing pressure on vegetation (Orr 1980). However, patch grazing is not controlled and can result in a decline in palatable plants, pasture condition (Bryant et al. 1989; Dowling et al. 2005) and environmental degradation (Trlica 1977; Asner et al. 2004).
Rotational grazing involves the concentration of livestock into a single paddock at higher stocking densities for a short period of time, after which the stock are moved into another paddock and the previously grazed paddocks are rested. Rotational grazing requires a number of smaller paddocks and the duration of grazing and rest is determined by the number of paddocks in a rotation (in time-based rotations) and the growth rate of the pasture and FOO (in flexible rotational systems). Smaller paddocks improve the spatial efficiency and forage utilisation of animals as every part of a landscape tends to be explored by livestock, access to forage is maximised, whilst high stocking densities can substantially reduce livestock selectivity (Norton 1998). The intensity and location of animal grazing can be modified by managers by the frequency, duration and timing of grazing and rest (Scarnecchia and Kothmann 1982; Kemp 1994; Kemp et al. 1996; Dowling et al. 2006). High stocking densities can lead to the defoliation of less preferred species and a comparative reduction in grazing pressure of preferred species.

Results from studies of the effect of grazing systems on a pastoral ecosystem have been highly variable in terms of pasture composition and plant and animal production. The results are complicated by a plethora of factors that include variability of management practices and environments, species of animal, climatic conditions, study duration, study methodologies and whether treatments are replicated.

Within Australia studies of sheep grazing improved pastures have reported increased forage production and available herbage mass under RG than CG (Warn et al. 2002), although animal live weight between the systems can remain comparable in a deferred rotation (Lloyd-Davies and Southey 2001) and a fixed and variable rotation (Chapman et al. 2003). Similarly, Morley et al. (1969) reported comparable animal production between continuous and tactical RG management systems and an inconsistent effect on forage production. In contrast, Holst et al. (2006) and Waller et al. (2001) recorded higher BCS in tactically grazed and higher live weight of rotationally grazed ewes, respectively, in comparison to ewes managed within a CG system. Studies within native pastures have reported greater forage production under a fixed-RG system but no difference in individual animal live weight (Lodge et al. 2003a; 2003b). In an unreplicated study (Dowling et al. 2006) within a tactical RG system after 18 months significant pasture compositional changes were observed, with an increase in preferred palatable perennial pasture species and a decline in undesirable pasture species.
However, the effect was transient as there were no differences in pasture production or composition between the two management systems after six years. There have been few studies that have investigated intensive rotational grazing systems.

Similarly, inconsistent results of the effect of RG and CG on animal and pasture production and vegetation composition have been recorded in international studies in sheep and cattle. Little to no difference was recorded in the vegetation between RG and CG under a flexible RG system (Gutman and Seligman 1979; Gutman et al. 1990) or short-duration grazing system (Bertelsen et al. 1993; Hart et al. 1993a; 1993b) nor in animal production between the grazing systems (Gutman and Seligman 1979; Bertelsen et al. 1993; Hart et al. 1993a; 1993b). In a number of studies a fixed RG system (Sharrow and Krueger 1979; Sharrow 1983) and a short duration grazing system (Walton et al. 1981) resulted in greater forage production and trends in greater live weight gain (Sharrow and Krueger 1979; Walton et al. 1981; Heitschmidt et al. 1982a; 1982b; Sharrow 1983).

The majority of grazing studies have failed to clearly demonstrate a significant benefit of RG over CG on animal production, in contrast to the reports of producers in Australia, South Africa and North America that claim improved species composition, land productivity and an increase in SR (Norton 2003). This may reflect the constraints in much research where rotation patterns may not be as flexible as applied on farms and that treatment effects may only be starting to emerge at the time experiments conclude. The benefits of a grazing system can be judged in terms of effects on animal production, vegetation or some other parameters including increased SR.

In this chapter differences in animal production (live weight, BCS and wool production and quality of ewes and the live weight of their lambs) between low intensity (CG) and high intensity (RG) grazing systems are investigated. The differences between grazing systems are discussed, whilst specific issues are explored in greater detail in later chapters. It was hypothesised that the average live weight, BCS and wool production of CG (and the live weight of their lambs) would be greater than RG ewes.
4.2 Materials and methods

4.2.1 Site and animal management
This experiment was conducted at the Central Tablelands EverGraze Proof Site, at Panuara in NSW. General site description, management and climate recordings have been previously outlined in Chapter 3, section 3.1.

4.2.2. Animal measurements
All animals were randomly allocated to the treatment groups and replicates at the commencement of the experiment at the site (in 2008). Each treatment replicate was ‘balanced’ for single and multiple pregnancies following pregnancy scanning in June, after which SR adjustments were made to achieve the same potential number of lambs per ewe in each group. Average monthly ewe live weight and BCS and lamb live weight were calculated. Ewe wool was periodically dye-banded during the 2010 production year and wool mid-side samples were harvested in May of 2010 and 2011.

4.2.2.1 Live weight and body condition score
Average monthly ewe live weight and BCS were calculated for the period following weaning (mid - December) to six weeks pre-partum (mid - July) of each production year, to reduce conceptus effects. Ewe live weight data was adjusted to account for monthly wool growth effects. Similarly, average lamb live weight was calculated from the first weighing post-partum (August - September) to weaning (in mid - December 2008, 2010 and 2011 and mid-November in 2009).

Further details of the methods are outlined in Chapter 3, section 3.1.4.2.

4.2.2.2. Wool growth and production
Individual wool samples were harvested from ewes prior to shearing in May of 2010 and 2011. Wool grown during 2009 – 2010 and harvested in 2010 was dye-banded on three occasions. Refer to Chapter 3, sections 3.2.2.2 and 3.2.2.3 for further details of wool dye-banding and fleece weight and growth study methods, respectively. Individual wool samples were sent for analysis and the analytical procedures are outlined in Chapter 3, sections 3.5.1.1 to 3.5.1.3.
4.2.3. Temperature and rainfall data
Meteorological data was collected from January 2008 to December 2011. Rainfall (total and intensity), temperature, solar radiation, relative humidity, and wind speed were recorded on an automatic weather station at 15 minute intervals.

The rainfall and average minimum and maximum temperatures for the study period (January 2008 – December 2011) are shown in Figure 4.1. The highest and lowest annual rainfall was recorded in 2010 (1108 mm) and 2009 (540 mm), respectively. The average annual rainfall during the study period was 986 mm, approximately 153 mm higher than the long-term average for the site. The above average rainfall was largely influenced by the high rainfall in 2010. Similar to the long-term average rainfall data (see section 3.1.1, Figure 3.1) rainfall was distributed throughout the year with little seasonal variation evident during the study period.

4.2.4. Statistical analysis
Individual animal data was analysed to determine any effects of treatment block and replicate. A ewe’s pregnancy status (twins or single) was included in the analysis of ewe live weight and birth type (twin or single) was included in the analysis of lamb birth and live weight. Any differences in wool fibre diameter between treatments (CG vs. RG)
and years (wool harvested in 2010 vs. 2011) was analysed using a linear mixed model that included a cubic spline of distance from the tip of the staple (Verbyla et al. 1999), with estimations via REML that was fitted to the data to test for effects of treatment groups and measurement intervals (fixed effects) while allowing for random animal effects (Gloag and Behrendt 2002).

Treatment means for all parameters were analysed using ANOVA (Genstat® 13th edn, Hemel Hempstead United Kingdom) and differences were significant when p < 0.05.

4.3 Results

4.3.1. Stocking rate

The average annual SR (dry sheep equivalent (DSE)/ha) of the two grazing treatments are outlined in Table 4.1. The SR of 2008 and 2009 were similar (p > 0.05) between systems. However, in 2010 and 2011 the SR of the RG system was higher (p < 0.05) than the CG system.

Table 4.1. Average (± SE) annual stocking rate* (DSE/ha, where 1 DSE was equivalent to a dry, not pregnant 50 kg ewe with a BCS 3.0) and average annual live weight (± SE) of ewes managed within differing grazing management systems. *Stocking rates were decided based on a flexible approach that considered forage available (further details are outlined in Chapter 3, section 3.1.4.2).

<table>
<thead>
<tr>
<th></th>
<th>CG (± SE)</th>
<th>RG (± SE)</th>
<th>Difference (CG - RG)</th>
<th></th>
<th>CG (± SE)</th>
<th>RG (± SE)</th>
<th>Difference (CG - RG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>9.0 ± 0.13a</td>
<td>9.5 ± 0.13a</td>
<td>-0.5</td>
<td>2009</td>
<td>5.1 ± 0.24a</td>
<td>6.6 ± 0.18a</td>
<td>-1.5</td>
</tr>
<tr>
<td>2010</td>
<td>5.2 ± 0.12a</td>
<td>7.7 ± 0.15b</td>
<td>-2.5</td>
<td>2011</td>
<td>5.0 ± 0.26a</td>
<td>6.7 ± 0.28b</td>
<td>-1.7</td>
</tr>
</tbody>
</table>

*ab values in the same row (and column for live weight) with a different superscript are significantly different (p < 0.05)

4.3.2 Live weights and body condition scores

The average annual SR (Table 4.1) includes ewes and lambs within each grazing system, whereas the live weight and BCS data of ewes reported in Table 4.1 and the following section (4.3.2.1) is limited to reduce conceptus effects. The reported time period of ewe live weight and BCS for each production year is from mid - December (following weaning) to mid - July (six weeks pre-partum). Lamb live weights reported in section 4.3.2.3 are from birth (August) to weaning (November – December) of each production year.
4.3.2.1 Live weights

The average annual ewe live weight and average monthly live weight of ewes managed within the differing grazing systems are shown in Table 4.1 and Figure 4.2, respectively.

The average live weight of ewes managed within the CG system was consistently greater ($p < 0.001$) each year. For both management systems live weight between years was different ($p < 0.001$); the lowest average live weight of animals was recorded in 2009 (CG = 55.3 kg and RG = 53.7 kg) that corresponded to the lowest annual rainfall and in case of RG animals the lowest SR. The highest average live weight of animals was recorded in 2010 (CG = 67.8 kg, RG = 64.1 kg) that coincided with the highest annual rainfall.

At the start of the study (December 2008) the average ewe live weight was 54 (± 1.1) kg (with seven months of wool growth) and was similar ($p > 0.05$) between management systems. In 2009 the average live weight of CG ewes was higher than RG ewes in January ($p < 0.05$), March ($p < 0.05$) and December ($p < 0.05$). Similarly, in 2010 the average live weight of ewes managed within the CG system was greater than ewes managed within the RG system in January ($p < 0.05$), March ($p < 0.001$) and December ($p < 0.05$), following weaning (December and January) and prior to joining in March and April. In 2011 the average live weight of CG ewes was also greater than RG ewes at each weighing ($p < 0.05$ January, February and May; $p < 0.001$ March, June and July).

A similar trend in ewe live weight was observed throughout the year. The differences in ewe live weight between grazing systems were greatest following weaning in January and March of 2009 and December to March of 2010. During June of 2010 there was a significant difference in live weight between the RG and CG ewes and the differences between the systems remained following weaning in December 2010 and throughout 2011.
Figure 4.2. Average (± SE) monthly live weight of ewes managed within differing grazing systems over time. CG (green); RG (blue). * p < 0.05; ** p < 0.001.

4.3.2.2 Ewe BCS

The average annual BCS and average monthly BCS of ewes managed within the differing grazing systems followed a similar trend to the live weight of the ewes (within the contrasting grazing systems) over time and are shown in Table 4.2 and Figure 4.3, respectively.

In both 2010 and 2011, the average annual BCS was consistently higher for CG ewes than RG ewes (p < 0.001 in 2010 and 2011). However, the BCS of the two groups of ewes was similar (p > 0.05) in 2009 when SR was also similar (p > 0.05). The highest BCS was recorded in 2010 that corresponded to the highest ewe live weight and highest annual rainfall. The lowest BCS of CG ewes was recorded in 2009 when the lowest live weight of the animals was also recorded together with the lowest annual rainfall and highest SR. In RG ewes the lowest BCS was recorded in 2011, when the stocking rate of RG animals was greater (p < 0.05) than CG ewes (6.7 vs. 5.0 DSE/ha; or 25% higher).

The monthly BCS of both groups of ewes was comparable from December 2008 to July 2009. However, following weaning in December of 2009 the BCS of ewes managed within the CG system was greater (p < 0.001) than ewes managed within the RG system as well as in January (p < 0.001), March (p < 0.001) and June (p < 0.01) of 2010.
Similarly, the BCS of CG ewes was higher in December of 2010 (p < 0.01) as well as in January, February, March and June (p < 0.001) of 2011.

**Table 4.2.** Average (± SE) annual body condition score of ewes managed within differing grazing systems, 2009 to 2011.

<table>
<thead>
<tr>
<th>Grazing treatment</th>
<th>Body condition score</th>
<th></th>
<th></th>
<th>LSD (5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2009</td>
<td>2010</td>
<td>2011</td>
<td></td>
</tr>
<tr>
<td>CG</td>
<td>3.3 ± 0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.8 ± 0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.4 ± 0.08&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.23</td>
</tr>
<tr>
<td>RG</td>
<td>3.1 ± 0.05&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.4 ± 0.03&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.9 ± 0.05&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.16</td>
</tr>
</tbody>
</table>

*a-e values in the same row or column with a different superscript are significantly different (p < 0.001)

**Figure 4.3.** Average (± SE) monthly body condition score (BCS) of ewes managed within differing grazing systems over time. CG (green); RG (blue). * p < 0.05; ** p < 0.001.

### 4.3.2.3 Lamb live weight

The average annual weaning live weight of lambs, lambs/ha and lambs/ewe managed within the differing grazing systems are shown in Table 4.3 and the average monthly live weight of lambs is shown in Figure 4.4.

The number of lambs per ewe was similar (p > 0.05) between grazing systems as was the number of lambs per ha in 2008 and 2009; however the average live weight of CG lambs was 2.1 kg heavier than RG animals. During 2010 and 2011 the number of lambs per ha within the RG system was greater (p < 0.05) but the average live weights of the lambs managed within the CG system were 3.1 kg and 1.7 kg greater than RG lambs, respectively.
The average annual live weight of lambs was similar between years and grazing systems (p > 0.05). However, the average monthly live weight of CG lambs was greater than (p < 0.05) RG lambs at each weighing until weaning, with the exception of birth weight which was similar (p > 0.05) each year and the live weight of lambs in December 2008. In December 2008 the live weight of lambs within the contrasting systems was similar (p > 0.05) (CG = 34.1 kg vs. RG = 32.8 kg) as a result of a greater (p < 0.001) live weight gain of RG lambs from the previous month (3.3 kg vs. 1.4 kg).

Table 4.3. Average (± SE) annual weaning live weight, lambs/ha and lambs/ewe of lambs managed within differing grazing systems 2008 to 2011.

<table>
<thead>
<tr>
<th>Year</th>
<th>Weaning live weight (kg)</th>
<th>Lambs / ha</th>
<th>Lambs / ewe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CG</td>
<td>RG</td>
<td>CG</td>
</tr>
<tr>
<td>2008</td>
<td>34.0 ± 0.59</td>
<td>32.8 ± 0.62</td>
<td>5.7 ± 0.17</td>
</tr>
<tr>
<td>2009</td>
<td>31.3 ± 0.78</td>
<td>26.6 ± 0.58</td>
<td>5.6 ± 0.42</td>
</tr>
<tr>
<td>2010</td>
<td>36.3 ± 0.72</td>
<td>30.9 ± 0.64</td>
<td>3.9 ± 0.42</td>
</tr>
<tr>
<td>2011</td>
<td>32.8 ± 0.66</td>
<td>29.5 ± 0.55</td>
<td>4.6 ± 0.44</td>
</tr>
</tbody>
</table>

Values in the same row (ab) or column (ABC) with a different superscript are significantly different (p < 0.05)

Figure 4.4. Average (± SE) live weight of lambs managed within differing grazing systems over time. CG (green); RG (blue). * p < 0.05.

4.3.3 Wool growth and production
For clarity of presentation dye-banded wool harvested in 2010 (grown between May 2009 and May 2010) is referred to as 2010 wool. Wool harvested in 2011 and grown
between May 2010 and May 2011 (non dye-banded wool) is referred to as 2011 wool. Individual wool samples sent for analysis were from ewes managed within the grazing systems at the site for greater than 10 months of the production year and resulted in a total of 43 samples from both 2010 (CG n = 17; RG n = 26) and 2011 (CG n = 18; RG n = 25).

The analysed wool production and quality parameters are shown in Table 4.4.

4.3.3.1 Wool production and yields
Average greasy fleece weights (GFW) were higher (p < 0.001) in 2010 (5.2 ± 0.11 kg) compared to 2011 (4.0 ± 0.08 kg). Average clean fleece weights (CFW) were also greater (p < 0.001) in 2010 (3.5 ± 0.10 kg) than in 2011 (3.0 ± 0.06 kg). Similarly, wool yields were greater (p < 0.05) in 2011 (74.6 ± 0.45%) than 2010 (70.1 ± 0.56%). However, there were no differences (p > 0.05) between grazing management systems for GFW, CFW and wool yields (Table 4.4).

For 2010 the average total wool base yield (of dye-banded samples) was greater (p < 0.05) in ewes managed within the RG system (74.7 ± 0.52%) than CG ewes (74.7 vs. 72.8%). However, there were no differences (p > 0.05) between the grazing systems in terms of wool yield with each dye-band section.

Table 4.4. Average (± SE) wool production and quality parameters of sheep managed within differing grazing systems for wool harvested at shearing in May 2010 and 2011.

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CG</td>
<td>RG</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>RG</td>
</tr>
<tr>
<td>Wool production parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GFW (kg/hd)</td>
<td>5.4 ± 0.21a</td>
<td>5.0 ± 0.16a</td>
</tr>
<tr>
<td>CFW (kg/hd)</td>
<td>3.7 ± 0.20a</td>
<td>3.5 ± 0.16a</td>
</tr>
<tr>
<td>Wool yields (%)</td>
<td>70.0 ± 1.06a</td>
<td>71.4 ± 0.86a</td>
</tr>
<tr>
<td></td>
<td>4.1 ± 0.15b</td>
<td>3.9 ± 0.12b</td>
</tr>
<tr>
<td></td>
<td>3.0 ± 0.12b</td>
<td>2.9 ± 0.09b</td>
</tr>
<tr>
<td></td>
<td>77.1 ± 0.54b</td>
<td>75.6 ± 0.70b</td>
</tr>
<tr>
<td>Wool base yields (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total yield</td>
<td>72.7 ± 0.64a</td>
<td>74.7 ± 0.51b</td>
</tr>
<tr>
<td>Base to third dye-band (Mar 10)</td>
<td>72.9 ± 1.29a</td>
<td>74.6 ± 1.05a</td>
</tr>
<tr>
<td>Mid 1 – third second dye-band (Dec 09)</td>
<td>72.4 ± 1.29a</td>
<td>74.7 ± 1.05a</td>
</tr>
<tr>
<td>Mid 2 – second first dye-band (Oct 09)</td>
<td>73.5 ± 1.29a</td>
<td>75.04 ± 1.05a</td>
</tr>
<tr>
<td>Tip - first dye-band to tip (May 09 – Oct 09)</td>
<td>72.1 ± 1.29a</td>
<td>74.4 ± 1.05a</td>
</tr>
<tr>
<td>Wool quality parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATLAS measurements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staple length (mm)</td>
<td>107.9 ± 2.43a</td>
<td>105.8 ± 1.96a</td>
</tr>
<tr>
<td>Staple strength (N/kt)</td>
<td>21.8 ± 2.10a</td>
<td>22.3 ± 1.70a</td>
</tr>
<tr>
<td>POB (mm)</td>
<td>17.3 ± 2.11a</td>
<td>18.7 ± 1.71a</td>
</tr>
<tr>
<td>OFDA2000 fibre diameter (μm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>19.1 ± 0.35a</td>
<td>18.5 ± 0.28a</td>
</tr>
<tr>
<td>Minimum</td>
<td>17.0 ± 0.35a</td>
<td>16.5 ± 0.28a</td>
</tr>
<tr>
<td>Maximum</td>
<td>21.2 ± 0.39a</td>
<td>20.4 ± 0.31a</td>
</tr>
</tbody>
</table>

ab values in the same row with a different superscript are significantly different (p < 0.05)
4.3.3.2 Wool quality and growth

The average wool quality parameters for all animals are shown in Table 4.5. The average staple length was longer (p < 0.001) in 2010 than 2011 and the average staple strength was greater (p < 0.05) in 2011 than 2010. The average POB along the staple varied (p < 0.001) between 2010 and 2011, however, the average staple length, strength and POB was similar (p > 0.05) between the animals managed within differing grazing systems (Table 4.4). The average fibre diameter did not differ (p > 0.05) between 2010 (18.6 ± 0.19 μm) and 2011 (18.9 ± 0.19 μm). Although the average minimum fibre diameter along the staple was lower (p < 0.001) in 2010 than in 2011 and the maximum fibre diameter along the staple was similar (p > 0.05) between 2010 and 2011. Neither the minimum or maximum fibre diameter varied (p > 0.05) between animals managed within differing grazing management systems.

Table 4.5. Average (± SE) wool quality parameters of all animals for wool harvested at shearing in May 2010 and 2011.

<table>
<thead>
<tr>
<th>ATLAS measurements</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staple length (mm)</td>
<td>106.9 ± 1.26a</td>
<td>93.7 ± 1.35b</td>
</tr>
<tr>
<td>Staple strength (N/kt)</td>
<td>22.2 ± 1.42a</td>
<td>27.1 ± 1.43b</td>
</tr>
<tr>
<td>POB (mm) from base of staple</td>
<td>19.7 ± 1.15c</td>
<td>37.9 ± 3.39d</td>
</tr>
<tr>
<td>OFDA2000 Fibre diameter (μm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>18.6 ± 0.19a</td>
<td>18.9 ± 0.19a</td>
</tr>
<tr>
<td>Minimum</td>
<td>16.7 ± 0.17c</td>
<td>17.5 ± 0.20d</td>
</tr>
<tr>
<td>Maximum</td>
<td>20.6 ± 0.21a</td>
<td>20.2 ± 0.20a</td>
</tr>
</tbody>
</table>

Values in the same row with a different superscript are significantly different a,b(p < 0.05); c,d(p < 0.001)

4.3.3.2 Fibre diameter variability along the staple

Fibre diameter was measured every 5 mm along a staple. Fibre diameter measurements from 100 mm onwards were excluded as sample sizes were too small for accurate statistical analysis. A comparison of the fibre diameter along the staple of ewes grazing within RG and CG systems during 2010 and 2011 is presented in Figure 4.5 and the CVFD of a staple is shown in Table 4.6.

The variability of fibre diameter was greater (p < 0.001) in 2010 (16.9 ± 0.21%) than 2011 (16.1 ± 0.22%). However, the variability of fibre diameter did not differ (p > 0.05) between grazing treatments.

During 2010 the average fibre diameter of the fleece of ewes managed within the CG system was greater than that of ewes managed within the RG at 80 mm to 65 mm (p < 0.05) along the staple.
Figure 4.5. Average fibre diameter along the staple (5 mm) of sheep managed within differing grazing systems. Section 1 (2010): wool growth from shearing in 2009 to shearing in 2010. Section 2 (2011): wool growth from shearing in 2010 to shearing in 2011. CG (green); RG (blue). * p < 0.05.

Table 4.6. Average (± SE) coefficient of variation of fibre diameter (%) within a staple for sheep managed within differing grazing systems.

<table>
<thead>
<tr>
<th></th>
<th>CG</th>
<th>RG</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>16.9 ± 0.33a</td>
<td>16.9 ± 0.27a</td>
</tr>
<tr>
<td>2011</td>
<td>15.9 ± 0.32b</td>
<td>16.2 ± 0.27b</td>
</tr>
</tbody>
</table>

\textit{ab} values in the same row or column with a different superscript are significantly different \((p < 0.05)\)

4.4 Discussion

All animals were removed from the experimental site during June and July of 2009 as a result of a management decision to conserve forage at the site and ensure minimum FOO targets (outlined in Chapter 3, section 3.1.4.2) were met during lambing. All animals regardless of grazing system were treated the same and as a consequence the results of 2009 were influenced by the management of the ewes.
4.4.1 Stocking rate
The SR of CG animals did not vary between years following a reduction in SR in 2009. In contrast the SR of RG system varied over time and similarly decreased in 2009, increased in 2010 before a subsequent decline in 2011. The increase in SR in 2010 was associated with higher rainfall and pasture growth within the system. However, the higher FOO also resulted in a slower rotation of animals within the system and a reduction in pasture quality (Badgery, unpub. data).

4.4.2 Live weight and body condition score
Ewes managed within the CG system consistently outperformed RG ewes in terms of live weight, BCS and lamb live weight.

Ewe live weight and BCS between years varied significantly (p < 0.05); the highest live weight and BCS were recorded in 2010, which had the highest annual rainfall. Thus the higher live weight and BCS of ewes in 2010 is likely to be a result of greater quantities of quality vegetative green feed associated with higher rainfall. The higher FOO within the RG system resulted in a slower rotation of the animals within the system and as a consequence a reduction in pasture quality that together with the higher SR of RG animals (≈ 33 % higher) may explain the lower live weight and BCS of the ewes in this system.

The lowest animal live weights, difference in live weight between grazing systems (1.6 kg/hd) and BCS of CG ewes were recorded in 2009, when the lowest annual rainfall was recorded. The SR differences between the CG and RG systems in 2009 and 2011 were similar (1.5 and 1.7 DSE/ha higher for RG animals, ≈ 23 - 25 % higher) and less than 2010 (that was 2.5 DSE/ha, ≈ 33 % higher for RG animals). In spite of this, the greatest differences in ewe live weight (5.5 kg/hd) and BCS (0.5) between grazing systems were recorded in 2011. Thus the results of 2009 are in part influenced by the removal of the animals from the grazing systems for two months in June and July. The SR of RG ewes in comparison to CG ewes in this study (23 – 33 % higher) was greater than the elevated carrying capacity of RG animals managed within a high intensity system in an improved, P fertilised pasture by Warn et al. (2002). The authors found carrying capacity could be increased by up to 17 – 21 % under high and low P fertiliser, respectively without compromising animal performance.

Similar to ewe live weight, the live weight and growth of CG lambs was consistently greater (p < 0.05) than RG lambs, even in 2008 when there was a similar stocking rate.
One exception was the growth of lambs between November and December of 2009, where the growth rate of RG lambs was higher \( (p < 0.05) \) despite the number of lambs per ha being similar \( (p > 0.05) \). The greater growth rate of RG lambs during this period as well as the smaller difference in ewe live weight between systems in April and May of 2009 and 2010 may be a consequence of greater FOO through summer and autumn by rationing available feed on offer and increasing growth over a longer period of time within the RG system. Greater FOO is a result of forage being held over from the management of animals’ grazing location and duration. This was particularly the case in 2009 when there was below average rainfall and thus limited forage. The recorded higher growth rate of RG lambs and reduced differences in ewe live weight in comparison to CG suggest a RG system may prove advantageous through summer and autumn.

Animal production is determined by the nutrient intake of an animal and the nutrient intakes of grazing animals depend on the amount and nutrient content of plant species and plant parts the animal eats (Mayes and Dove 2000). The greater live weight and BCS of CG ewes and the greater growth rate and live weight of lambs from the CG systems are influenced by SR, but are also likely to be a result of a higher diet quality and/or higher feed intake. The greater production of CG ewes from 2009 onwards may be attributed to the lower SR of the animals and the associated higher feed availability for individual animals together with the animals’ ability to selectively graze within the landscape in comparison to the animals managed within the RG system. The results of this study indicate the live weight, BCS and lamb growth of animals managed within differing grazing systems are not simply a result of differences in SR. This was most notably demonstrated in 2011 when differences in SR were reduced and the greatest difference in live weight and BCS between the systems was recorded. Thus further investigation of diet quality and selection as well as the grazing location of the animals managed within these contrasting grazing systems is essential. In particular, the intake and diet quality (and selection) of sheep managed within differing grazing systems and how this may change seasonally warrants investigation as well as that of the landscape use of free-ranging animals in order to better manage animals within flexible RG grazing systems.
4.4.3 Wool growth and production

Overall wool production and growth was greater (p < 0.05) in 2010 than 2011 in terms of GFW (5.2 kg vs. 4.0 kg, respectively), CFW (3.5 kg vs. 3.0 kg, respectively), and staple length (106.9 mm vs. 93.7 mm, respectively). However, wool yields were higher (p < 0.05) in 2011 than 2010 (74.6 vs. 70.1 %, respectively). The average and maximum fibre diameters were similar between years, however, greater variability (p < 0.001) in fibre diameter was recorded in 2010 (16.9 vs. 16.1 %) in comparison to 2011. Whilst the minimum fibre diameter was smaller (p < 0.05) in 2010 than 2011 (16.7 vs. 17.5 μm) staple strength was greater (p < 0.05) in 2011 than in 2010.

Changes in fibre diameter along a staple are primarily the result of variability of secondary follicles that are sensitive to changes in nutrition (Lyne 1964). Changes in fibre diameter and staple strength have been highly correlated with a sheep’s diet (Sharkey et al. 1962; Nagorcka 1977; Reis 1979). Fibre diameter is a major determinant of staple strength and a large fibre diameter is generally associated with a higher staple strength. However, staple strength is also determined by variations in fibre diameter where high variability in fibre diameter along a staple will result in a weaker fibre than a fibre with a uniform diameter along the staple (Reis 1992). Thus, the stronger staple produced in 2011 (27.1 vs. 22.2 N/kt) is likely to be a consequence of the lower variability of fibre diameter (along the staple) together with the higher minimum fibre diameter (Reis 1992). The greater variation in fibre diameter of 2010 wool is likely to be a result of a variable feed availability and variable nutrient supply resulting from the low rainfall and high temperatures of 2009 together with the high rainfall and lower temperatures of 2010.

A lag period exists between the effect of diet and intake on wool growth and fibre diameter of approximately 28 and 35 days, respectively (Nagorecka, 1977). The POB occurred later in the production year in 2010 than 2011 (19.7 mm vs. 37.9 mm from the base of the staple) and is associated with the increased nutrient demands of pregnancy and lactation in both years. The POB in 2010 wool is associated with the high nutrient demands of late lactation three months prior in approximately November - December of 2009. The average POB in 2011 (37.9 mm along the staple) is likely to be associated with the high nutrient requirements of late pregnancy and/or early lactation in August to September of 2011. The difference between years and the earlier effect of pregnancy and lactation in 2011 may be a result of the lower body weight (thus body reserves) of
the animals in comparison to the previous year and associated with a lower diet quality of the animals.

There was little difference (p > 0.05) in wool growth and production between the grazing management systems. The average wool base measurement of dye-banded samples was greater (p < 0.05) in wool harvested from RG ewes than CG ewes in 2010 and a trend was observed of higher wool yields in RG ewes; however, there was no difference (p > 0.05) in wool base measurements between the systems for any of the dye-banded sections or in overall wool production. The average fibre diameter of 2010 wool harvested from CG ewes was significantly greater at three points along the staple than RG ewes; however, the average fibre diameter and CVFD were similar (p > 0.05) between the grazing management systems. The lack of difference in wool production between grazing systems agrees with the findings of Warn et al. (2002) of sheep managed within contrasting grazing systems in an improved fertilised pasture.

In terms of wool the production year had a greater impact on growth and production than grazing systems. However, it must be acknowledged that the sample sizes of the study were limited (n = 43 in total) and larger sample sizes are recommended for future work.

4.5 Conclusion

Overall, the live weight and BCS of CG ewes and the growth rate of their lambs were consistently superior to those of RG ewes and their lambs. These differences are likely to be the result of a higher diet quality of CG animals as a consequence of both the lower SR of the CG system and the animals’ ability to selectively graze within the landscape. The higher production of CG animals may also be influenced by the lower SR of the system and the associated higher feed availability for individual animals. The wool growth and production of ewes managed within the differing grazing systems was similar. The greater impact on wool characteristics appeared to be production year and very likely the FOO and climate associated with each year. The observed differences in live weight and BCS of animals managed within the contrasting grazing systems are significant and a greater understanding of how management systems influence the quality of the diet and behaviour of animals grazing within heterogenous native pastures is essential to the further development and refinement of management practices and decisions. Thus further work investigating the diet quality and selection of animals within these differing grazing systems was completed. The diet selection and quality of
ewes grazing within the same native pasture was examined (Chapters 5 and 6) and within the differing grazing systems (Chapter 7). The grazing location and landscape use of ewes managed within the CG system was explored when the ewes were lactating with lambs at foot and when dry and not pregnant (Chapter 8). These studies were undertaken in order to further understand how free-ranging animals utilise a landscape and the underlying reasons for the recorded differences in animal production between the systems.
Chapter 5. Variation in the Nutrient Intake of Grazing Sheep

5.1 Introduction
Livestock grazing in diverse grasslands in variable landscapes are confronted with a wide variation in the quantity and quality of forage on offer. This can result in significant differences in nutrient intake, in part due to differences in selectivity. Differences in the degree of selectivity and preferences between species of grazing animals are well recognised. Research suggests that the inter-individual variation between animals of the same flock or herd in terms of diet selection, forage preferences, intake, grazing behaviour and nutrient requirements is considerable (Arnold 1964; Marten 1978).

Individual animal variation is an important consideration in experimental design to ensure the number of animals is sufficient to account for inter-animal variation and must be considered when allocating animals to experimental groups (Prache et al. 2006). When investigating diet selection by sheep in the field, Arnold (1964) found that the intake of green grass within a predominately dead pasture varied considerably (10 - 80% of diet) as did the N content of the ingested plants (3.2 - 4.6%). Prache et al. (2006) similarly reported substantial inter-individual variation in the preference and consumption of *Lolium perenne* and *Festuca arundinacea* by ewes. This variation between what animals ingest also extends to supplements. Scott and Provenza (1999) found considerable variability in the intake of lambs offered high energy (barley 221-991 g/d) and high protein (lucerne/alfalfa 51-558 g/d) feeds. They also found that the overall nutrient intake (CP and digestible energy (DE)) of lambs did not change when they were fed a diet that contained lower concentrations of CP and DE than their preference. These findings support those of Kyriazakis and Oldham (1993) who found that lambs selected a diet that met their CP requirements but avoided excessive protein intake.

Few studies to date have investigated variation in the nutritive value of the diet of grazing animals using non-invasive methodologies or spatially segregated feeds. Previous work has concentrated on restricted diet options and/or the use of oesophageal-fistulated animals. Determining diet selection and nutrient intake of grazing animals without interfering with their normal grazing behaviour is inherently difficult,
particularly within heterogeneous pastures such as native grasslands. Oesophageal-fistulated sheep are of use in intensive grazing experiments, but their use is limited in extensive grazing situations and further limited by practical and welfare concerns (Le Du and Penning 1982). Lee and MacGregor (2004) examined the use of n-alkanes in sheep grazing pasture containing lucerne, native grasses and forbs and concluded that alkanes in isolation are unlikely to provide a good estimation of the diet selected by sheep grazing heterogeneous pastures. The poor estimation of diet composition was attributed to the large number of species present, insufficient differences in the concentration of the available alkanes between plant species and insufficient alkanes to account for a large number of botanical components within a heterogeneous pasture. Furthermore, variation in the age and proportion of plant parts within species affects the concentration and distribution of alkanes within a plant to such an extent that different parts of the same species need to be considered as separate components of the pasture (Dove 1996) and thus render alkanes unsuitable for use within complex native pastures.

Native grasslands can contain 10 - 20 species of similar plant functional types, each contributing more than 5% of the total biomass.

Alternative ways of assessing intake include non-invasive methods of determining diet selection and diet quality and involve various faecal analyses. Diet selection may be determined by microscopic identification of plant species in faecal material, which is very laborious and time-consuming. Faecal DNA has potential application for determining the components of the grazing animal’s diet but requires the prior establishment of a DNA reference bank of all the plant species present in the pasture (Ho et al. 2010). However, faecal analysis, based on either chemical parameters (Mahipala et al. 2009) or NIRS can be successfully used to determine diet quality (Lyons et al. 1995; Valiente et al. 2004; Coates and Dixon 2008; Dixon and Coates 2008, Kumara Mahipala et al. 2010). Faecal NIRS relies upon a calibration database that includes animals consuming similar pasture from the studied region (Coates 2000); relevant calibration data is currently unavailable for the pastures common to the studied area.

The primary objective of the research presented in this chapter was to determine, using intensive pasture monitoring and plant quality analysis, the degree to which diet composition and quality varies between two groups of ewes grazing within a heterogeneous pasture. A second aim was to examine faecal chemistry analysis as a
methodology to assess the quality of the diet of grazing ewes and to determine the number of animals required to create a bulk faecal sample that would be indicative of the nutrient quality of the diet of a sheep grazing as a group of up to 25 animals. It was hypothesised that the composition and quality of the diet of individual ewes and two groups of ewes would be significantly different.

5.2 Materials and methods

5.2.1 Site location, experimental design and climate data
The experiment was conducted from 26th August to 9th September 2010 at the EverGraze Central Tablelands Proof Site. Refer to Chapter 3, section 3.1 for information on experiment location and details of site management.

Four replicate plots, 0.08 ha (20 m x 40 m), were established within a native grassland in October 2009. The plots were paired based upon available forage and similar botanical compositions (plots 1 and 3, and 2 and 4, respectively were paired) and were grazed by two groups of 10 dry Merino ewes (CentrePlus®) at a SR of 125 DSE/ha over a period of 9 days.

The four plots had previously been grazed in pairs at the same SR a 190 days prior to this study. For this experiment, the first two plots (1 and 3) were grazed for 5 days, after which the animals grazed the remaining two plots (2 and 4) for 4 days (d 6 to 9). The duration of grazing was based upon FOO within each plot (with the aim of having a residual FOO of no less than 1000 kg DM/ha per plot). Group 1 grazed plots 1 and 2 and Group 2 grazed plots 3 and 4.

5.2.1.1 Climatic data
Climatic data including temperature, relative humidity, rainfall and wind speed was recorded every 15 minutes at the site (Figure 5.1). The average daily temperature for the 9 days of the experiment in August – September of 2010 was 8°C (range: 1 - 19°C), the relative humidity was 88% (range: 40 - 100%) and the average wind speed was 17 km/h (range: 2 - 38 km/h). A total of 48 mm of rainfall was recorded during the experiment.

5.2.2 Animals
Twenty dry Merino ewes were randomly selected from a flock of sheep grazing at the site and were familiar with the pasture. All of the ewes were four years of age with an average live weight of 61 (± 3.5) kg, BCS of 3, with 3.5 months of wool growth. The
ewes were randomly allocated to one of two groups. Individual animals were clearly marked with large individual numbers on their side using stock spray marker.

**Figure 5.1.** Daily rainfall (columns) and average (blue), maximum (green) and minimum (purple) temperatures during the study period (2010) and timing of grazing and faecal sampling. ↑ Timing of faecal sampling.

### 5.2.3 Pasture biomass, phenology and species selection

Pasture biomass and composition was assessed using the same 0.25 m$^2$ (0.5 m x 0.5 m) quadrat at 36 permanent points per plot, arranged in a regular grid, prior to and following grazing. The total, green and dead biomass was estimated by direct visual assessment (kg DM/ha) (Campbell and Arnold 1973). The botanical composition of each quadrat was estimated by direct visual assessment of the green and dead components of all species present within a quadrat (kg DM/ha) (Campbell and Arnold 1973). At the initial pasture assessment (prior to grazing) the developmental stage of each species was recorded as; vegetative (V), reproductive (R) and senescent (Sc). Refer to Chapter 3, section 3.3.1.1 for further details of pasture assessment methods.

During grazing the pasture was assessed daily and a grazing rating was assigned to the green and dead components of each species according to a grazing rating index (Chapter 3, section 3.3.1.1 and Figure 3.3). The grazing rating ranged from zero where no grazing was evident to five where plants were severely grazed with > 81% of the plants’ original biomass removed and only the stems and basal material remained.
5.2.4 Estimated diet composition

The average daily composition of the diet of each group of ewes was estimated from the pre- and post-grazing biomass together with the average daily grazing rating that identified the plant species consumed by the animals and the extent to which each species within each quadrat was grazed. The contribution of each plant species to the daily intake of the animals within each plot was then calculated as a proportion (%) of the diet consumed each day.

5.2.5 Evaluation of the nutritive value of plant species components

Plant material of the major pasture species was hand-plucked from the plot area prior to grazing and additional samples were collected following daily identification of the pasture species and plant parts consumed by the animals for analysis of nutritive value. Refer to Chapter 3, section 3.3.1.3 for details of methods of sample collection and preparation.

5.2.6 Faecal sample collection

Daily, individual faecal samples were collected during a 2 h period at the same time each day (0900 h – 1100 h). The observer stood near or within the plot and when an animal defecated the animal’s individual number was recorded and the fresh sample collected from the pasture without delay, labelled and placed in a cooled, portable ice box prior to drying. Samples were collected from four individual ewes within each plot for the duration of grazing and four subsequent days after the completion of grazing to account for the rate of passage of digesta. The faecal samples were oven-dried at 60°C on the day of collection for 48 h and then ground through a 1 mm screen using a hammer mill (Humboldt Mfg Co. IL, USA) before chemical analysis.

Individual variation in diet quality of a total of seven ewes (Group 1; n = 4, Group 2; n = 3) was examined at three time points; days 5, 10 and 14. Data for one ewe in Group 2 was only available for days 10 and 14. The rumen retention time of digesta of sheep has been estimated by Huston et al. (1986) as approximately 37 h and Simao Neto et al. (1987) estimated the average total passage rate of digesta in sheep based upon the passage of undigested seed as 62 h and up to 96 h. An important influence on the rate of passage of digesta is the characteristics of the diet. A study of changes in the dietary organic matter digestibility (OMD) of ewes grazing the studied pasture indicated an approximate rate of digesta of 60 - 72 h (refer to Appendix B for further details). Thus...
the quality of an animal’s diet on day 5 coincides with the first two days of the animal’s grazing the first plot (days 1 and 2 of grazing). Day 10 approximates the first two days the animals commenced grazing the second plots (2 and 4) (days 6 - 7 of grazing) and day 14 corresponds to the final day the animals grazed the second plots (days 9 - 10 of grazing).

5.2.7 Plant and faecal chemical analysis
Analyses of the vegetation samples included N, ash, DMD, DOMD and ME. The analysis of faecal matter included fN, fNDF, fADL and fAsh. Refer to Chapter 3, section 3.5.2 for details of analytical procedures.

5.2.8 Estimation of daily nutrient intake
Individual ewe intake and maintenance requirements were predicted using the decision support tool GrazFeed® (Freer et al. 2010) that incorporated the pasture DMD, weather conditions (maximum temperature 19ºC; minimum temperature 1ºC; average wind speed 17 km/h and rain fall 3 mm) and ewe condition during the study period. The daily intake of ME and DMD of the two groups of ewes was estimated from the predicted intake (kg DM/d) together with estimated diet composition of the two groups and the nutritive value of the harvested plant species. The quantity of green and dead DM within the pasture was included in the model; however, the quality of dead DM was not analysed at the time and as a consequence a value for dead DMD within GrazFeed® of 40% was applied based upon previous analysis of pasture samples harvested at the site (Badgery unpub. data).

5.2.9 Examination of faecal chemistry predictive equations
The animals’ dietary OMD and ME were estimated using equations derived by Mahipala et al. (2009) and dietary OMD was also estimated by an equation developed by Wang et al. (2009). The predictive equations derived by Mahipala et al. (2009) were as follows:

\[
\text{OMD}_M (\text{g/kg DM}) = 814.55657 - 514.4869 (f\text{ADL} / f\text{NDF}) - 0.93196 (f\text{Ash}) - 5.4971 (f\text{N})
\]

\[
\text{Diet ME}_M (\text{MJ/kg DM}) = 12.32323 - 8.25181 (f\text{ADL} / f\text{NDF}) - 0.01522 (f\text{Ash}) - 0.07933 (f\text{N})
\]
The predictive model of diet OMD developed by Wang et al. (2009) used the following formula:

\[ \text{OMD}_W = 0.899 - 0.644 \times \exp\left(-0.5774 \times \text{faecal CP (g/kg OM)/100}\right). \]

Refer to Chapter 3, section 3.6.2 for details of how these equations were developed.

The OMD and ME of the diet consumed by individual ewes on three days of grazing (days 1-2, 6-7 and 10 from faecal samples collected on days 5, 10 and 14, respectively) using faecal predictive equations were calculated. The predicted ME\textsubscript{M} of the diet was converted to ME\textsubscript{M} intake based upon the GrazFeed\textsuperscript{®} predicted intake of 1.17 kg DM/ewe. The values predicted by Mahipala et al. (2009) for OMD\textsubscript{M} and ME\textsubscript{M} intake and the values predicted by Wang et al. (2009) for OMD\textsubscript{W} were compared to the DMD and ME intake values estimated for days 1-2, 6-7 and 9-10 from intensive pasture monitoring, estimated diet composition together with pasture quality analyses.

### 5.2.10 Statistical analysis

All data was analysed using Genstat\textsuperscript{®} (13\textsuperscript{th} edn, Hemel Hempstead United Kingdom) and significant results and relationships were identified when \( p < 0.05 \). Pasture biomass pre- and post-grazing data for each plot and grazing period was determined and analysed using ANOVA. Comparative analysis of faecal chemistry predictive equations was completed using regression analysis.

Data for the diet quality (ME and OMD) of individual ewes within each group (plot) and between the two groups (\( n = 8 \)) was analysed using ANOVA. The relationships between the percentage of herbage consumed and the initial green to dead ratio and pasture DOMD were analysed using regression analysis. The number of animals required to obtain a representative bulk sample of a group of up to 25 animals was determined using variance component analysis.

### 5.3 Results

#### 5.3.1 Pasture biomass and phenology

The pasture species within the plots are listed in Table 5.1. The major pasture species accounted for 92% of the pasture. The contribution of the major pasture species to the diet of the two groups of grazing ewes was estimated by the combination of pre- and post-grazing composition data and the daily grazing rating assessments.
The average (± SE) pasture biomass of the four plots prior to grazing was 2183 (± 71) kg DM/ha which was comprised of 1017 (± 28) kg green DM/ha, 202 (± 13) kg litter DM/ha and with a groundcover of 92 (± 0.8) %.

**Table 5.1.** Major and minor pasture species (and developmental stage). Minor plant species were those <5% of total biomass.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Major pasture species</th>
<th>Minor pasture species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasses (native – C3)</td>
<td><em>Austrodanthonia</em> spp. (V)</td>
<td><em>Austrostipa</em> spp. (R)</td>
</tr>
<tr>
<td></td>
<td><em>Elymus scaber</em> (V)</td>
<td><em>Microlaena stipoides</em> (late V)</td>
</tr>
<tr>
<td>Grasses (native – C4)</td>
<td><em>Bothriochloa macra.</em> (Sc)</td>
<td></td>
</tr>
<tr>
<td>Grasses (introduced – C3)</td>
<td><em>Lolium rigidum</em> (V)</td>
<td><em>Holcus lanatus</em> (R)</td>
</tr>
<tr>
<td></td>
<td><em>Poa bulbosa</em> (V)</td>
<td></td>
</tr>
<tr>
<td>Other monocotyledons (introduced)</td>
<td><em>Juncus</em> spp. (Sc)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Asphodelus fistulosus</em> (R)</td>
<td></td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td><em>Hypochaeris radicata</em> (V)</td>
<td><em>Acetosella vulgaris</em> (V)</td>
</tr>
</tbody>
</table>

**5.3.2 Pasture composition**

Pre- and post-grazing total and green herbage mass of each species as well as litter and ground cover (%) are presented for Group 1 (Table 5.2) and Group 2 (Table 5.3).

Following grazing in all plots the total and green herbage mass (p < 0.001) as well as litter (plots 1 and 3, p < 0.001; plots 2 and 4, p < 0.05) was reduced. The total and green pasture biomass reduction and the estimated average daily disappearance of total and green herbage for an individual ewe based on the effective stocking rate of 125 DSE/ha (50 kg ewe) are presented for each plot in Table 5.4 and for the two groups of ewes in Table 5.5. There were significant differences (p < 0.001) in the total and green herbage reduction between plots 1 and 3 and plots 2 and 4 that were reflected in average daily disappearance of pasture from these plots. However, the differences between the total and green biomass reduction and the average daily disappearance of green and dead herbage between the two groups of ewes were not significant (p > 0.05). The predicted DM intake of an individual ewe grazing the pasture from GrazFeed® was 1.17 kg DM.

When Group 1 grazed plot 1 the green herbage mass of *M. stipoides*, *Austrodanthonia* spp., *H. radicata* and *L. rigidum* were reduced (p < 0.05). Similarly, following the grazing of plot 2 the green herbage mass of *Austrodanthonia* spp. and *E. scaber* (p < 0.001) and *H. radicata* (p < 0.05) were reduced. Following the grazing of plot 3 by Group 2 green *M. stipoides* and *H. radicata* (p < 0.001) and the green of *Austrodanthonia* spp., *E. scaber* and *L. rigidum* (p < 0.05) were reduced as was the dead components of *M. stipoides* and *L. rigidum* (p < 0.05). In plot 4 after grazing green *H.
radicata (p < 0.001) and green Austrodanthonia spp. and E. scaber (p < 0.05) had declined as had the dead components of Austrodanthonia spp. and E. scaber (p < 0.05).

5.3.3 Estimated diet composition
The estimated composition of the diet consumed by Group 1 and Group 2 ewes is shown in Figures 5.2 and 5.3, respectively. For Group 1 ewes, the majority of the diet on the first day of grazing consisted of the green vegetative material of Austrodanthonia spp. (22% of the diet), M. stipoides (17%), L. rigidum (17%) and H. radicata (12%) that represented 9%, 21%, 7% and 4% of the available pasture DM biomass, respectively. Thus, the ewes displayed strong selection of green Austrodanthonia spp., L. rigidum and H. radicata and included these species within their diet in proportions that were twice the availability of these species within the pasture. Strong selection of green E. scaber, H. radicata and Austrodanthonia spp. was also evident on day 6; on the first day of grazing plot 2 the ewes selected Austrodanthonia spp. (39% of diet), E. scaber (26%), M. stipoides (12%) and H. radicata (9%) that accounted for 27%, 10%, 9% and 2% of the pasture, respectively.

On the first day of grazing the diet of Group 2 ewes consisted predominantly of green M. stipoides (26%), H. radicata (23%), Austrodanthonia spp. (14%) and E. scaber (11%) that comprised 27%, 5%, 5% and 4% of the available pasture, respectively. The animals exerted strong selection for green H. radicata, Austrodanthonia spp. and E. scaber and consumed these species at approximately three times their availability within the pasture. Similar strong selection was exerted by the animals for green H. radicata, E. scaber and L. rigidum on day 6, the first day of grazing plot 4. The contribution of H. radicata, L. rigidum, E. scaber and Austrodanthonia spp. to the animal’s diet was 33%, 21%, 21% and 18%, respectively; however, the contribution of these species to the total available pasture biomass was considerably less, at 7%, 7%, 9% and 15%, respectively.
Table 5.2. Group 1: Average (± SE) pre- and post-grazing biomass and the proportion the species contributed to the pasture.

<table>
<thead>
<tr>
<th></th>
<th>Herbage mass (kg DM/ha)</th>
<th>Proportion of pasture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Pre-grazing</td>
<td>Post-grazing</td>
</tr>
<tr>
<td></td>
<td>(kg DM/ha)</td>
<td>(kg DM/ha)</td>
</tr>
<tr>
<td></td>
<td>(Proportion of pasture %)</td>
<td>(Proportion of pasture %)</td>
</tr>
<tr>
<td>Plot 1 (d 1 - 5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2515 ± 195.0</td>
<td>1361 ± 143.8</td>
</tr>
<tr>
<td>Green</td>
<td>1108 ± 68.4</td>
<td>501 ± 49.3</td>
</tr>
<tr>
<td>Litter</td>
<td>237 ± 24.8</td>
<td>130 ± 13.5</td>
</tr>
<tr>
<td>Cover (%)</td>
<td>92 ± 1.4</td>
<td>92 ± 1.4</td>
</tr>
</tbody>
</table>

| Native grasses (C3)   | Microlaena stipoides    | Green                     | Dead                     |
|                       |                         | 469 ± 68.8                | 632 ± 102.1              |
|                       |                         | (20.6)                    | (27.7)                   |
|                       |                         | 267 ± 45.5                | 413 ± 67.2               |
|                       |                         | (21.7)                    | (33.6)                   |
|                       |                         | 155 ± 35.3                | 130 ± 35.6               |
|                       |                         | (9.2)                     | (7.7)                    |
|                       |                         | 93 ± 23.3                 | 80 ± 23.3                |
|                       |                         | (6.6)                     | (8.3)                    |

| Austrodanthonia spp.  | Green                    | 216 ± 52.8                | 135 ± 31.8               |
|                       |                         | (9.5)                     | (5.9)                    |
|                       | Dead                    | 76 ± 20.5                 | 76 ± 17.5                |
|                       |                         | (6.2)                     | (6.2)                    |
|                       |                         | 456 ± 50.1                | 331 ± 52.7               |
|                       |                         | (27.0)                    | (20.0)                   |
|                       |                         | 232 ± 29.2                | 212 ± 36.7               |
|                       |                         | (24.0)                    | (21.9)                   |

| Austrostipa spp.      | Green                    | 43 ± 20.0                 | 52 ± 21.8                |
|                       |                         | (1.9)                     | (2.3)                    |
|                       | Dead                    | 14 ± 7.7                  | 23 ± 9.8                 |
|                       |                         | (1.1)                     | (1.8)                    |
|                       |                         | 62 ± 15.2                 | 160 ± 46.0               |
|                       |                         | (3.7)                     | (9.4)                    |
|                       |                         | 53 ± 13.7                 | 124 ± 36.6               |
|                       |                         | (5.5)                     | (12.9)                   |

| Elymus scaber         | Green                    | 49 ± 20.1                 | 35 ± 15.6                |
|                       |                         | (2.2)                     | (1.5)                    |
|                       | Dead                    | 9 ± 4.3                   | 20 ± 9.9                 |
|                       |                         | (0.7)                     | (1.6)                    |
|                       |                         | 175 ± 29.8                | 150 ± 31.6               |
|                       |                         | (10.3)                    | (8.9)                    |
|                       |                         | 58 ± 11.4                 | 104 ± 19.5               |
|                       |                         | (6.0)                     | (10.8)                   |

| Native grasses (C4)   | Bothriochloa macra      | Green                     | Dead                     |
|                       |                         | 0 ± 0.0                   | 0 ± 0.0                  |
|                       |                         | (0.0)                     | (0.0)                    |
|                       |                         | 0 ± 0.0                   | 0 ± 0.0                  |
|                       |                         | (0.0)                     | (0.0)                    |
|                       |                         | 0 ± 0.0                   | 0 ± 0.0                  |
|                       |                         | (0.0)                     | (0.0)                    |

| Introduced grasses (C3)| Lolium rigidum     | Green                     | Dead                     |
|                       |                         | 153 ± 44.2                | 48 ± 16.1                |
|                       |                         | (6.7)                     | (2.1)                    |
|                       | Dead                    | 44 ± 18.3                 | 22 ± 6.4                 |
|                       |                         | (3.5)                     | (1.8)                    |
|                       |                         | 4 ± 2.8                   | 1 ± 0.6                  |
|                       |                         | (0.2)                     | (0.1)                    |
|                       |                         | 1 ± 0.5                   | 0 ± 0.0                  |
|                       |                         | (0.1)                     | (0.0)                    |

| Poa bulbosa          | Green                    | 35 ± 6.6                  | 6 ± 2.6                  |
|                       |                         | (1.5)                     | (0.3)                    |
|                       | Dead                    | 21 ± 4.2                  | 2 ± 1.4                  |
|                       |                         | (1.7)                     | (0.2)                    |
|                       |                         | 14 ± 4.6                  | 4 ± 2.8                  |
|                       |                         | (0.9)                     | (0.3)                    |
|                       |                         | 11 ± 3.4                  | 3 ± 2.3                  |
|                       |                         | (1.1)                     | (0.3)                    |

| Holcus lanatus       | Green                    | 3 ± 1.8                   | 1 ± 0.5                  |
|                       |                         | (0.1)                     | (0.0)                    |
|                       | Dead                    | 2 ± 0.9                   | 0 ± 0.3                  |
|                       |                         | (0.1)                     | (0.0)                    |
|                       |                         | 0 ± 0.3                   | 0 ± 0.0                  |
|                       |                         | (0.0)                     | (0.0)                    |

| Other monocotyledons (introduced) | Juncus spp. | Green | Dead |
|                                   |             | 53 ± 36.6 | 196 ± 105.5 |
|                                   |             | (2.3)    | (8.6)     |
|                                   |             | 40 ± 26.6 | 148 ± 79.2 |
|                                   |             | (3.3)    | (12.0)    |
|                                   |             | 0 ± 0.0   | 0 ± 0.0    |
|                                   |             | (0.0)    | (0.0)     |
|                                   |             | 0 ± 0.0   | 0 ± 0.0    |
|                                   |             | (0.0)    | (0.0)     |

| Asphodelus fistulosus  | Green        | 3 ± 1.3     | 2 ± 0.9     |
|                       | Dead         | 2 ± 1.9     | 1 ± 1.4     |
|                       |             | 0 ± 0.0     | 0 ± 0.0     |
|                       |             | (0.0)       | (0.0)       |

| Forbs (introduced)    | Hypochaeris radicata | Green | Dead |
|                       |             | 94 ± 28.8 | 24 ± 8.4 |
|                       |             | (4.1)    | (1.0)    |
|                       |             | 25 ± 6.6 | 9 ± 3.5   |
|                       |             | (2.0)    | (0.7)    |
|                       |             | 37 ± 13.4| 7 ± 3.1   |
|                       |             | (2.2)    | (0.4)    |
|                       |             | 6 ± 3.0  | 3 ± 0.9   |
|                       |             | (0.6)    | (0.3)    |

| Acetosella vulgaris   | Green        | 3 ± 1.5     | 0 ± 0.3     |
|                       | Dead         | 0 ± 0.3     | 0 ± 0.3     |
|                       |             | 0 ± 0.1     | 1 ± 0.7     |

A superscript in the post-grazing column indicates a significant difference over time "* (p <0.05); "** (p < 0.001)
Table 5.3. Group 2: Average (± SE) pre- and post-grazing biomass and the proportion the species contributed to the pasture.

<table>
<thead>
<tr>
<th>Species</th>
<th>Plot 3 (d 1 to 5) Pre-grazing (kg DM/ha)</th>
<th>Post-grazing (kg DM/ha)</th>
<th>Pre-grazing (kg DM/ha)</th>
<th>Post-grazing (kg DM/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Herbage mass (kg DM/ha)</td>
<td>(Proportion of pasture %)</td>
<td>Herbage mass (kg DM/ha)</td>
<td>(Proportion of pasture %)</td>
</tr>
<tr>
<td>Microlaena stipoides</td>
<td>Green 580 ± 55.1</td>
<td>(26.7)</td>
<td>317 ± 36.3</td>
<td>(28.1)</td>
</tr>
<tr>
<td></td>
<td>Dead 790 ± 81.7</td>
<td>(36.4)</td>
<td>521 ± 55.5</td>
<td>(46.1)</td>
</tr>
<tr>
<td>Austrodonthia spp.</td>
<td>Green 105 ± 37.2</td>
<td>(4.8)</td>
<td>21 ± 6.6</td>
<td>(1.9)</td>
</tr>
<tr>
<td></td>
<td>Dead 77 ± 28.0</td>
<td>(3.5)</td>
<td>38 ± 13.1</td>
<td>(3.3)</td>
</tr>
<tr>
<td>Austrostipa spp.</td>
<td>Green 3 ± 2.7</td>
<td>(0.1)</td>
<td>1 ± 0.8</td>
<td>(0.1)</td>
</tr>
<tr>
<td></td>
<td>Dead 2 ± 1.7</td>
<td>(0.1)</td>
<td>1 ± 1.4</td>
<td>(0.1)</td>
</tr>
<tr>
<td>Elymus scaber</td>
<td>Green 94 ± 28.5</td>
<td>(4.4)</td>
<td>15 ± 4.7</td>
<td>(1.3)</td>
</tr>
<tr>
<td></td>
<td>Dead 62 ± 27.6</td>
<td>(2.9)</td>
<td>31 ± 17.1</td>
<td>(2.7)</td>
</tr>
<tr>
<td>Bothriochloa macra</td>
<td>Green 0 ± 0.0</td>
<td>(0.0)</td>
<td>0 ± 0.0</td>
<td>(0.0)</td>
</tr>
<tr>
<td></td>
<td>Dead 0 ± 0.0</td>
<td>(0.0)</td>
<td>0 ± 0.0</td>
<td>(0.0)</td>
</tr>
<tr>
<td>Lolium rigidum</td>
<td>Green 32 ± 10.9</td>
<td>(1.5)</td>
<td>5 ± 2.0</td>
<td>(0.4)</td>
</tr>
<tr>
<td></td>
<td>Dead 7 ± 3.2</td>
<td>(0.3)</td>
<td>3 ± 1.4</td>
<td>(0.3)</td>
</tr>
<tr>
<td>Poa bulbosa</td>
<td>Green 52 ± 7.9</td>
<td>(2.4)</td>
<td>34 ± 5.1</td>
<td>(3.0)</td>
</tr>
<tr>
<td></td>
<td>Dead 5 ± 1.1</td>
<td>(0.2)</td>
<td>0 ± 0.3</td>
<td>(0.0)</td>
</tr>
<tr>
<td>Holcus lanatus</td>
<td>Green 2 ± 1.4</td>
<td>(0.1)</td>
<td>2 ± 1.4</td>
<td>(0.2)</td>
</tr>
<tr>
<td></td>
<td>Dead 6 ± 3.9</td>
<td>(0.3)</td>
<td>3 ± 2.8</td>
<td>(0.3)</td>
</tr>
<tr>
<td>Juncus spp.</td>
<td>Green 38 ± 22.0</td>
<td>(1.7)</td>
<td>33 ± 18.4</td>
<td>(2.9)</td>
</tr>
<tr>
<td></td>
<td>Dead 61 ± 40.1</td>
<td>(2.8)</td>
<td>41 ± 26.9</td>
<td>(3.6)</td>
</tr>
<tr>
<td>Asphodelus fistulosus</td>
<td>Green 40 ± 11.2</td>
<td>(1.9)</td>
<td>17 ± 4.8</td>
<td>(1.5)</td>
</tr>
<tr>
<td></td>
<td>Dead 29 ± 7.2</td>
<td>(1.3)</td>
<td>16 ± 3.9</td>
<td>(1.4)</td>
</tr>
<tr>
<td>Hypochaeris radicata</td>
<td>Green 105 ± 21.5</td>
<td>(4.9)</td>
<td>15 ± 4.7</td>
<td>(1.4)</td>
</tr>
<tr>
<td></td>
<td>Dead 50 ± 18.8</td>
<td>(2.3)</td>
<td>10 ± 3.6</td>
<td>(0.9)</td>
</tr>
<tr>
<td>Acetosella vulgaris</td>
<td>Green 5 ± 1.9</td>
<td>(0.2)</td>
<td>1 ± 0.3</td>
<td>(0.1)</td>
</tr>
<tr>
<td></td>
<td>Dead 2 ± 0.9</td>
<td>(0.1)</td>
<td>1 ± 0.5</td>
<td>(0.1)</td>
</tr>
</tbody>
</table>

A superscript in the post-grazing column indicates a significant difference over time * (p < 0.05); ** (p < 0.001)
Table 5.4. Average (± SE) total and green herbage reduction (kg DM/ha) and average daily pasture disappearance per ewe (kg DM/ewe) by plot.

<table>
<thead>
<tr>
<th></th>
<th>Plot 1</th>
<th>Plot 2</th>
<th>Plot 3</th>
<th>Plot 4</th>
<th>p-value</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average herbage</td>
<td>Total</td>
<td>1154 ± 72.2^A</td>
<td>797 ± 47.7^B</td>
<td>1158 ± 54.2^A</td>
<td>782 ± 40.1^B</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>607 ± 42.5^A</td>
<td>444 ± 32.9^B</td>
<td>612 ± 40.5^A</td>
<td>452 ± 29.2^B</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Daily pasture</td>
<td>Total</td>
<td>1.8 ± 0.12^A</td>
<td>1.6 ± 0.10^B</td>
<td>1.9 ± 0.09^A</td>
<td>1.6 ± 0.08^B</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>1.0 ± 0.07</td>
<td>0.9 ± 0.07</td>
<td>1.0 ± 0.06</td>
<td>0.9 ± 0.06</td>
<td>0.667</td>
</tr>
</tbody>
</table>

^AB^ values in the same row with a different superscript are significantly different (p < 0.05)

Table 5.5. Average (± SE) total and green herbage reduction (kg DM/ha) and average daily pasture disappearance per ewe (kg DM/ewe) per group.

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average herbage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reduction</td>
<td>Total</td>
<td>976 ± 47.9</td>
<td>970 ± 40.2</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>525 ± 28.4</td>
<td>532 ± 26.6</td>
</tr>
<tr>
<td>Average daily pasture disappearance per ewe</td>
<td>Total</td>
<td>1.7 ± 0.08</td>
<td>1.7 ± 0.06</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>0.9 ± 0.05</td>
<td>0.9 ± 0.04</td>
</tr>
</tbody>
</table>

Figure 5.2. Contribution of the major, green pasture species to the composition of the diet of Group 1 ewes. Plot 1 (5 days of grazing) followed by plot 2 (4 days of grazing). *M. stipoides* (green); *Austrodanthonia* spp. (red); *E. scaber* (orange); *Austrostipa* spp. (blue); *L. rigidum* (grey); *H. radicata* (khaki)
Figure 5.3. Contribution of the major, green pasture species to the composition of the diet of Group 2 ewes. Plot 1 (5 days of grazing) followed by plot 2 (4 days of grazing). *M. stipoides* (green); *Austrodanthonia* spp. (red); *E. scaber* (orange); *Austrostipa* spp. (blue); *L. rigidum* (grey); *H. radicata* (khaki)

5.3.4 Pasture species quality analysis

The quality of the hand-plucked pasture species is shown in Table 5.6. The introduced grass species were of higher quality than the native grasses and were of similar quality to the species evaluated by Archer and Robinson (1988). The animals consistently selected *M. stipoides*, *Austrodanthonia* spp. that were in a reproductive and vegetative state of development, respectively and dominated the pasture. The perennial forb *H. radicata* in a vegetative stage of development recorded the highest DOMD, DMD, N content and ME of the analysed pasture samples and was avidly selected by the animals. *Lolium rigidum*, in a vegetative stage of development was proactively selected by the animals. *Elymus scaber* in a mature vegetative stage was consumed by the animals despite having the lowest quality of the plant species for all reported parameters. The initial pasture composition is an important consideration in the observed diet selection of the animals.
Table 5.6. Average (± SE) N content, DOMD, DMD and ME of green pasture species components.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Plant species</th>
<th>N (% )</th>
<th>DOMD (%)</th>
<th>DMD (%)</th>
<th>ME (MJ/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native grasses (C3)</td>
<td><em>M. stipoides</em></td>
<td>2.7 ± 0.09</td>
<td>58 ± 1.4</td>
<td>60 ± 1.6</td>
<td>8.8 ± 0.27</td>
</tr>
<tr>
<td></td>
<td><em>Austrodanthonia</em> sp.</td>
<td>1.8 ± 0.22</td>
<td>51 ± 0.9</td>
<td>52 ± 1.0</td>
<td>7.3 ± 0.15</td>
</tr>
<tr>
<td></td>
<td><em>Elymus scaber</em></td>
<td>1.3 ± 0.08</td>
<td>47 ± 2.0</td>
<td>48 ± 2.0</td>
<td>6.6 ± 0.40</td>
</tr>
<tr>
<td>Introduced grasses (C3)</td>
<td><em>Lolium rigidum</em></td>
<td>1.6 ± 0.19</td>
<td>60 ± 1.0</td>
<td>62 ± 1.3</td>
<td>9.1 ± 0.21</td>
</tr>
<tr>
<td></td>
<td><em>Holcus lanatus</em></td>
<td>2.6 ± 0.37</td>
<td>60 ± 2.7</td>
<td>63 ± 1.4</td>
<td>9.2 ± 0.58</td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td><em>Hypochaeris radicata</em></td>
<td>2.8 ± 0.15</td>
<td>61 ± 0.8</td>
<td>64 ± 0.9</td>
<td>9.4 ± 0.15</td>
</tr>
</tbody>
</table>

*ab* values in the same column with a different superscript are significantly different (p < 0.001)

5.3.5 Initial pasture composition and diet selection
The initial green to dead ratio of the DM of the major pasture species present within all plots, relative to the percentage of green forage consumed by the animals calculated from biomass assessments is shown in Figure 5.4. The positive exponential relationship between high levels of initial green to dead ratio of pasture species and high levels of percentage of green herbage consumed by the animals was highly significant (p < 0.001, adjusted $R^2 = 0.62$). A weaker, but significant relationship (p < 0.05) was identified between the DOMD of the initial pasture species and the percentage of green herbage consumed by the animals ($R^2 = 0.23$) (Figure 5.5). The relationship between high levels of initial green to dead ratio for the major grass species within the pasture and high levels of percentage of green herbage consumed by the animals was investigated and a positive linear relationship (p < 0.001, adjusted $R^2 0.57$) was identified (Figure 5.6).
The linear relationship identified that the positive exponential relationship (Figure 5.4) was largely influenced by green vegetative *H. radicata* and *L. rigidum*. No relationship (p > 0.05) was identified between the DOMD of the four major grass species and the percentage of green herbage consumed and no relationship (p > 0.05) was identified between the initial green biomass of the major plant species and animal consumption.
Figure 5.4. Relationship between initial green to dead ratio of the DM of the major pasture species and the percentage of green herbage consumed by the animals. (p < 0.001; \( R^2 = 0.62 \)). *M. stipoides* (green); *Austrodanthonia* spp. (red); *E. scaber* (orange); *Austrostipa* spp. (blue); *H. radicata* (yellow) and *L. rigidum* (grey).

Figure 5.5. Relationship between initial DOMD of the major pasture species and the percentage of green herbage consumed by the animals. (p < 0.05; \( R^2 = 0.23 \))
Figure 5.6. Relationship between initial green to dead ratio of the DM of the four major grass species and the percentage of green herbage consumed by the animals. (p < 0.001; R² = 0.57). *M. stipoides* (green); *Austrodanthonia* spp. (red); *E. scaber* (orange); *Austrostipa* spp. (blue)

5.3.6 Variation in diet quality between groups

The calculated DMD and ME intake of the diets of the two groups of ewes based upon the GrazFeed® estimated daily of intake 1.17 kg of DM is shown in Figure 5.7. The average, estimated ME intake of the two groups of animals was similar (p > 0.05) as was the average DMD (p > 0.05) which followed the same trend as ME intake. ME intake and DMD were highest on the first day of the animals entering a plot (day 1 and 6 of grazing) and declined over the duration of the grazing of each plot. The average estimated ME intake of the animals in Group 1 and Group 2 was 11.8 MJ and 12.2 MJ, respectively *i.e.* approximately 1.5 MJ above maintenance requirements (GrazFeed®, 10.5 MJ). The calculated DMD of the diet from pasture analyses of the two groups was similar; 55% for Group 1 ewes and 57% for Group 2 ewes. This estimated digestibility of the diet was very similar to the 55% predicted by GrazFeed®.
5.3.7 Comparison of faecal chemistry predictive equations for individual ewe data

The calculated DMD, predicted OMD and the calculated and predicted ME_M intake values of each grazing group from faecal analysis and the corresponding grazing days are shown in Tables 5.7 and 5.8, respectively. The calculated average DMD from pasture analyses was higher (p > 0.05) for Group 2 (60%) than Group 1 (55%). The average predicted OMD_M values were higher (p < 0.001) for Group 1 (88%) than Group 2 (80%) and the predicted values were greater than the calculated DMD values (p < 0.001). Similarly, the predicted OMD_W values were greater (p < 0.001) for Group 1 (62%) than Group 2 (59%) and were greater (p < 0.001) than the calculated DMD and less (p < 0.001) than the predicted OMD_M values.

The calculated ME intake from pasture analyses of ewes within Group 2 (12.7 MJ/d) was higher (p > 0.05) than the intake of ewes within Group 1 (11.8 MJ/d). The predicted ME_M intake of ewes within Group 2 (6.0 MJ/d) was higher (p > 0.05) than the predicted intake of ewes grazing within Group 1 (5.5 MJ/d). The predicted ME_M intake values were less than (p < 0.001) the calculated ME intake values (11.8 and 12.7 vs. 5.5 and 6.0 MJ/d, respectively). However, the rank order of the two groups was the same in each case.
Figure 5.7. Daily calculated diet DMD and ME (from pasture analyses) of the diet of Group 1 (blue) and Group 2 (red) ewes.
Table 5.7. Average (± SE) diet DMD (calculated from pasture analyses) and predicted OMD (from faecal chemistry equations) for each grazing group.

<table>
<thead>
<tr>
<th>Diet parameter</th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMD (%)</td>
<td>55 ± 1.6&lt;sup&gt;aA&lt;/sup&gt;</td>
<td>60 ± 1.7&lt;sup&gt;aA&lt;/sup&gt;</td>
</tr>
<tr>
<td>OMD&lt;sub&gt;M&lt;/sub&gt; (%)</td>
<td>88 ± 0.7&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>80 ± 0.7&lt;sup&gt;BB&lt;/sup&gt;</td>
</tr>
<tr>
<td>OMD&lt;sub&gt;W&lt;/sub&gt; (%)</td>
<td>62 ± 0.6&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>59 ± 0.6&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Values in the same row (ab) or column (ABC) with a different superscript are significantly different (p < 0.001).

*<i>n = 3 for 1 day of faecal collection</i>.

Table 5.8. Average (± SE) calculated ME intake (MJ/d/ewe) (from pasture analyses) and predicted MEM (from faecal chemistry equations) for each grazing group.

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME</td>
<td>11.8 ± 0.30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.7 ± 0.31&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>MEM</td>
<td>5.5 ± 0.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.0 ± 0.23&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>ab</sup> values in the same row or column with a different superscript are significantly different (p < 0.001).

*<i>n = 3 for 1 day of faecal collection</i>.

A positive non-linear relationship (double Fourier) was identified between OMD<sub>M</sub> and calculated DMD (p < 0.001; R<sup>2</sup> = 0.54); and MEM and calculated ME (p < 0.001; R<sup>2</sup> = 0.57) and a positive relationship (quadratic by quadratic) was identified between OMD<sub>W</sub> and DMD (p < 0.001; R<sup>2</sup> = 0.67). The R<sup>2</sup> values of the relationships were lower than desirable for a predictive function; however, the R<sup>2</sup> values for OMD<sub>W</sub> (0.67) and MEM (0.57) indicate a good relationship and provide a means of investigating trends in diet quality over time.

The estimated DMD and ME intake as well as predicted diet OMD<sub>M</sub>, OMD<sub>W</sub> and MEM intake of individual ewes and the two groups is shown in Figure 5.8. The predicted OMD<sub>M</sub> of the diet was very high and did not reflect the digestibility values of the available pasture and estimated DMD values that increased over time. The predicted OMD<sub>W</sub> of the diet was similar to the estimated DMD of the diet. However, neither the predicted OMD<sub>M</sub> nor OMD<sub>W</sub> reflected changes in the predicted ME intake or the estimated DMD values of the two groups of ewes.

The trend in MEM intake of the animals appears to reflect the movement of the animals between plots, with the highest MEM intake occurring on days 6 and 7 of grazing when the animals entered a new plot and then subsequently declined over the grazing period of the plot. The average MEM intake reflected the trends of the estimated ME intakes of...
the two groups of animals, with a higher (p > 0.05) predicted ME intake of Group 2 ewes than Group 1 ewes. However, the predicted $\text{ME}_M$ intake of the ewes would be sub-maintenance and is substantially less than the estimated quality of the pasture species.

### 5.3.8 Faecal samples required to obtain a representative group sample

In small plot studies, with limited numbers of animals there is concern about optimising the number of animals so that treatment comparisons are valid. In this research faecal samples were used to estimate the nutritive value of the forage eaten. The data obtained was then used to estimate variability and the number of samples required. Standard errors were derived for different sample sizes used to estimate $\text{OMD}_M$, $\text{OMD}_W$ and $\text{ME}_M$ (Figure 5.9). In these cases errors were minimal with a sample size of 5. The average standard error of variation for five ewes for $\text{OMD}_M$ and $\text{OMD}_W$ was 1.34% and for $\text{ME}_M$ was 0.41 MJ/kg DM.
Figure 5.8. Comparison of a) predicted diet OMD_M of individual ewes Group 1 (blue); Group 2 (red); b) predicted diet OMD_W of individual ewes Group 1 (blue); Group 2 (red); c) estimated diet DMD (squares) and ME (triangles) of Group 1 (blue) and Group 2 (red); d) predicted ME_M intake of individual ewes over time Group 1 (blue); Group 2 (red)
Figure 5.9. Standard error (variation) of a) Diet OMD\textsubscript{W} of individual ewes grazing within a group b) Diet ME\textsubscript{M} of individual ewes grazing within a group.
5.4 Discussion
The results of this study show that sheep were primarily selecting herbage based upon the green to dead DM ratio of a species, rather than nutrient content of a species and it was possible to successfully estimate the diet composition and intake of two groups of dry, not pregnant ewes grazing small plots within a native grassland. There was very little variation in the quality of the diet between the two groups, and as a consequence it was concluded that a representative sample for up to 25 sheep may be obtained from the collection of individual faecal samples from five animals. Furthermore, the applicability of faecal chemistry predictive equations was investigated and equations were identified that provide a means of qualitative comparisons of the quality of the diet of grazing animals, but the need to further investigate the accuracy of these measurements means quantitative comparisons are not possible.

5.4.1 Estimated diet composition and intake
The average composition of the diet consumed by the ewes varied between the two groups. However, despite the differences in diet composition between the groups there were no significant differences (p > 0.05) in the calculated average intake of ME or the DMD of the consumed diet of the two groups. The lack of variation in these parameters between animals and groups of animals may reflect that the ewes had similar nutrient requirements and grazed to meet their nutritional requirements from the available pasture and not necessarily the same diet composition.

The estimated daily herbage disappearance per ewe of 1.7 kg DM was above the GrazFeed® predicted daily DM intake (1.17 kg DM) for a ewe grazing the pasture. The visual estimation method may have overestimated total DM reduction in particular for the dead component of the pasture. A similar result has been previously observed in the same pasture (Badgery, unpub. data). However, in this study the difference of 0.53 kg DM equates to a ‘wastage’ component of ~30%, which is at the lower end of the range often used to account for trampling, plant breakdown and other damage from the grazing process (Burns et al. 1989). The estimated green herbage disappearance of 0.9 kg DM/ewe appears to be a good estimation of intake of the pasture component, suggesting that the additional 0.8 kg DM was mainly the lower quality forage components.
5.4.2 Pasture composition and diet selection

Both groups of ewes primarily selected the green vegetative forage within the pasture, although diet composition varied over time. Intake of green vegetative material was highest on the first day of grazing a plot (days 1 and 6 of grazing) and subsequently declined over time, as less green DM was available. There was good evidence that the observed initial selection of green vegetative forage by the animals was related to the initial green to dead ratio of the forage of a species, rather than the DOMD or other inherent nutritive value of a species. The animals maximised the consumption of a species when the initial green to dead DM ratio for that species was 3 or greater. A higher ratio of green to dead forage is typical of plants in a vegetative state and would allow the animals to select standing green herbage from dead herbage and consequently consume greater quantities of green relative to dead herbage. This relationship may in part explain the initial greater consumption of *Austrodanthonia* spp. than *M. stipoides* of Group 1 ewes despite the higher biomass and quality (higher N and OMD and lower ME) of the latter species. The positive exponential relationship between the initial green to dead ratio of the major pasture species and the consumption of green forage by the animals indicates that plants species with a greater proportion of green to dead forage will be consumed to a greater degree by the animals than plants with a lower ratio of green to dead forage. The proportion of green to dead forage may be a means by which sheep generally select more leaf than stem material and more green than dead material than the average pasture when grazing. The underlying mechanisms of this selection are not fully understood and are thought to be related to high intake rates (Kenney and Black 1984) that are associated with taller plants, high herbage mass and bulk density within a pasture (Hodgson 1982), rather than the *in vitro* digestibility of the pasture (Arnold 1981; Kenney and Black 1984). Selection is further influenced by the spatial arrangement of leaves within a pasture (Hodgson 1985) and the structural strength of leaf and stem material as well as the surface characteristics of live and dead material (Heady 1975). Many of these studies have been conducted in sown, fertilised and predominately green pastures, whereas the work reported here has been conducted in a highly variable native grassland where the proportion of dead material is often higher. The proportion of green to dead forage and the spatial arrangement of forage components appear to have a greater influence on selection than the DOMD of the pasture as animals are unable to directly sense nutrients *per se* (Arnold 1981). However, ‘greenness’ or a high green to dead ratio of forage may be a visual cue or mechanism
the animals have established between vegetation within a pasture that is more likely to meet their requirements (Edwards et al. 1997). The high ratio of green to dead forage of a species and associated higher levels of consumption by the animals may also be associated with a higher intake rate potential of the species and/or DOMD (Kenney and Black 1984). The use of sensory cues, in particular associations of visual and/or olfactory cues with rewards (pasture that meets the animal’s requirements) are considered to be an important mechanism in complex pastures and within grazing management systems with substantial spatial and temporal variability. Within heterogenous landscapes and pastures and flexible rotational grazing systems, the use of spatial memory alone would be ineffective (Edwards et al. 1996; 1997; Dumont and Petit 1998).

These results together highlight the influence of the developmental growth stage of a species and the spatial arrangement of plant components within a pasture on the selection of grazing animals and indicate selection of grazing animals is modified by the relative proportions of different plant species or components and their distribution in space (Hodgson, 1982). The results presented here differ from those in the literature derived from higher quality and predominately green pastures. In sown, simple mixture pastures the cues for selection by animals of areas of high biomass and preferred species differ from highly variable native grasslands with relatively high levels of dead DM present. Within these native grasslands it appears the dominant cue for selection of sheep is the green to dead ratio of pasture.

5.4.3 Examination of faecal chemistry predictive equations
The calculated DMD and ME intake of the two groups of ewes reflected the observed changes in the consumed diet where diet quality was highest on the first day of the animals grazing a plot and subsequently declined over the duration of the plot grazing with the highest DMD and ME intake occurring on day 6 of grazing when the animals were moved to a new plot.

The predicted OMD_M and OMD_W of the diets of the two groups of ewes were significantly different (p < 0.001) from the estimated DMD. However, significant relationships identified between the predicted OMD_M and OMD_W and the calculated DMD had good correlations (R^2 = 0.54 and 0.67, respectively). The predicted OMD_W values better reflected the trends in calculated DMD values than the OMD_M values. However, the predicted values of a higher OMD_M and OMD_W of Group 1 ewes was the
opposite of the higher average (p > 0.05) DMD of the diet of Group 2 ewes and neither of the predicted values reflected the estimated changes in ME intake of the animals over time. The predicted ME$_M$ intake values were significantly lower (p < 0.001) than the estimate ME intake values but appeared to be correlated ($R^2 = 0.57$) with the estimated ME values and mirrored the trends of the estimated ME intake of the two groups of ewes and the movement of animals between plots. The recorded trends in ME$_M$ intake together with good correlations with estimated ME intake may provide a means of comparing trends but not absolute values in ME intake of animals. In comparison, the predicted OMD$_M$ values and trend of increased OMD of the diet of the animals over time did not reflect the movement of animals between plots or the predicted ME value of the diet and intake of the animals and warrants further investigation.

It must be noted the equations used to calculate the diet quality of the ewes in this experiment were derived from heterogeneous feeds that included native and introduced pastures, browse species, oaten hay, alfalfa and soybean concentrate. Furthermore, the equations of Mahipala et al. (2009) were derived from ME values calculated on the basis of *in vitro* net gas production, rather than DOMD typically used for forages (Tilley and Terry 1963). The equations do provide a methodology for comparing differences between grazing groups; however, further examination of the applicability of these equations to the studied pasture is essential due to the disparity in the derived values. This would enable determination of the accuracy of the recorded trends in ME$_M$ intake.

5.4.4 Faecal samples required to obtain a representative group sample
When examining the diet quality of a group of up to 25 sheep a representative sample may be obtained from the collection of individual faecal samples from five animals. However, it must be acknowledged that the estimated differences between samples have the inherent error of the predictive equations.

5.4.5 Findings and future recommendations
The results of this study show that whilst there were differences in the average composition of the diet selected by two groups of grazing ewes this was not reflected in the calculated DMD and ME of the consumed diet. The sheep were primarily selecting diets based on the green to dead DM ratio and the level of nutrients ingested was then somewhat a secondary consequence of that selection cue. The results suggest the animals displayed ‘nutritional wisdom’ and selected a diet that met their similar nutrient requirements (Provenza 1995) from differing diet compositions. The mechanisms and
possible ‘cues’ underlying the selection of the animals appear to be related to the ‘greenness’ or green to dead ratio of forage of a pasture species that is associated with high DOMD and may also be associated with higher intake rate potential of the species. Further investigation of diet composition and quality of animals grazing within the studied pasture is recommended in particular throughout the grazing season.

5.5 Conclusion
This study found the main cue relating to the selection of pasture species in this native grassland was the green to dead DM ratio of a species. Sheep were maximising their consumption of a species when the initial green to dead ratio was 3 or more. This cue appears to be more important than the inherent nutritive value of a species, although these factors are obviously linked. The consumed forage quality varied over time, but over the study period the average ME and DMD of the diet tended to remain similar between two groups of sheep. That suggests the sheep were able to exercise an important level of selectivity in this study, which meant they varied what they ate in order to optimise their intake of nutrients within the constraints of the area. The moderate quality levels of this grassland meant there were limits on the total amount of nutrients e.g. as indicated by ME, that they could consume. Their actual consumption was though above the average values for this grassland. In this native grassland the primary cue is the green to dead ratio and other factors (e.g. DOMD) then play a secondary role.
Chapter 6. Seasonal Diet Selection of Sheep Grazing a Native Pasture in the Central Tablelands of New South Wales

6.1 Introduction

Plant and animal interactions are complex, difficult to measure in grazing animals and are particularly complicated in extensive and/or heterogeneous environments such as native pastures and grasslands across variable landscapes. Native pastures and grasslands are one of Australia’s most extensive natural resources and occupy a large portion of the livestock production area of south-eastern Australia, including large areas of the Central Tablelands of NSW. It is well recognised that sheep selectively graze a pasture and select particular plant species in preference to others which can have a profound impact on pasture botanical composition, management and animal production. However, knowledge of the nutrition of grazing ruminants and in particular the nutrition and diet selection of sheep grazing within native pastures and grasslands is limited, which restricts the ability of livestock producers to make informed decisions about grazing systems and livestock management.

Determining the composition (i.e. selection) and quality of the diet of a grazing animal is inherently difficult as a trade-off exists between interfering with the animal’s normal grazing behaviour and obtaining accurate and precise measurements (Thomas et al. 2008). It is extremely difficult in extensive, heterogeneous environments and landscapes. Sheep are specific in their diet selection and have been observed to consume the green leaf material of a single plant while leaving the stem material ungrazed (Arnold 1960). The active selection of particular pasture species by grazing animals is not fully understood. Selection may be influenced by pasture quality traits including; high digestibility or nutritive value such as high N or ME content or water soluble carbohydrate concentration (Edwards et al. 1995). Animals may also actively select forage species and components with a high intake rate potential (Kenney and Black 1984) which can be influenced by proportions of different plant species or components and their distribution within a pasture (Hodgson 1982). The avoidance of a plant species and/or plant components is generally associated with its structural characteristics and/or chemical compounds including the lignification of plant tissues (Carter 1990), structural carbohydrate, toxin or chemical compound concentration as well as the presence of mechanical structures such as spikes, thorns, prickles, hairs (Cooper and Owen-Smith
1986; Gowda 1996), awns and burrs (Hodgson 1982). Furthermore, as the structural and chemical characteristics of a plant change with plant maturity, an animal’s selection and avoidance of a plant species and particular components will change over time (Heady 1964) and consequently consideration of the phenology of plants within grazing studies is essential.

The greater portion of studies concerned with diet selection of grazing ruminants has occurred in simple pasture compositions such as grass and legume pastures. Previous studies of the diet of grazing animals have determined diet selection and composition by various methods including direct observation of the grazing animals (Kassa et al. 2007; Osuga et al. 2008), changes in plant biomass within a paddock (Dowling et al. 2005), collection and identification of consumed material via oesophageal and ruminal cannulation (Squires and Siebert 1983; Squires and Low 1987), the sampling of ruminal fluid and the identification of plant material in ruminal contents (Mayes and Dove 2000) and within faeces (Holechek et al. 2004). Other faecal-based methods used have included the evaluation of plant and faecal alkanes (Dove and Mayes 1991), faecal NIRS analysis (Garnsworthy and Unal 2004; Dixon and Coates 2008) and the DNA profiling of plant and faeces (Ho et al. 2010). The direct observation of animals is a simple yet time-consuming method and the presence of an observer may affect the animal’s behaviour, whilst observations from a distance limit accuracy and would be unsuitable within heterogeneous pastures and extensive grazing situations. Measurements of plant biomass involve careful design and consideration of the sampling location, frequency of sampling and size of quadrat to ensure the sampling is appropriate for the area (Frame 1993; t’Mannetje 2000) and is typically limited to small areas due to the time-consuming nature of such measurements. Determining the diet selection of grazing animals from the examination of samples of grazed forage and ruminal fluid obtained from fistulated animals provides a more accurate method than measuring plant biomass and observing animal selection (Squires and Siebert 1983; Squires and Low 1987). The collection and identification of grazed material from oesophageal-fistulated animals can be particularly accurate when grazing animals are confined to small areas (McInnes et al. 1983) but is of limited use in extensive situations. The identification of plant material in ruminal contents and faeces of animals has been found to be difficult for particular plant species (Rosiere et al. 1975) and was found to not accurately estimate the animal’s intake of grasses and forbs (McInnes et al. 1983). Furthermore, oesophageal-fistulation only allows the examination of the
animal’s diet over brief periods of time and fistulated animals may graze differently from non-fistulated animals (Mayes and Dove 2000). The use of these methodologies is also limited by the highly invasive nature of surgical fistulation of animals and associated animal welfare considerations.

An alternative, relatively non-invasive method of estimating diet selection as well as intake is the evaluation of plant and faecal alkanes. Saturated hydrocarbons (or \textit{n}-alkanes) located within the cuticle wax of plants can be used to identify plants species and their proportions within an animal’s diet (Dove and Mayes 1991). However, variations can exist in the alkane concentration between individual plant parts of a single species (Dove 1996) as well as with plant age (Lee and MacGregor 2004). As a consequence the number of plant species and plant parts able to be studied is restricted and thus the use of alkanes is best suited to grasses and grass and legume pastures (Valiente \textit{et al.} 2004) and temperate pastures comprised of only a small number of plant species (Lee and MacGregor 2004).

Faecal NIRS analysis is a non-invasive method of determining the nutrient and botanical composition of a grazing animal’s diet (Garnsworthy and Unal 2004; Coates and Dixon 2008; Dixon and Coates 2008) and in particular determining the intake of C3 and C4 grass species (Dixon and Coates 2008). The technique relies upon an established plant and faecal NIRS database but as such a database does not exist for the study region this technique cannot be used. Similarly, DNA profiling of plant and faecal samples is still in development and relies upon an established plant DNA database (Ho \textit{et al.} 2010) that does not currently exist for the study region.

The aim of this study was to investigate the diet selection of sheep grazing a heterogeneous native pasture and to examine any changes in diet selection that occurred over time, including seasonally. Considering the advantages and limitations of the various techniques available, it was concluded the most suitable would be monitoring changes in the pasture biomass over time. Due to the intensive and time-consuming nature of this methodology the study area was restricted to small plots and the intensive grazing or ‘crash-grazing’ of the plots by the animals, similar to a study by Leigh and Holgate (1978) who examined plant species selection of sheep grazing a native pasture. The technique of ‘crash-grazing’ small areas allows the detailed examination of diet selection and grazing behaviour (Prache, \textit{et al.} 1998) and has been shown to provide similar but condensed patterns of diet selection to those that would be observed in
extensive situations (Leigh and Holgate 1978). Given the strong result from the previous chapter (Chapter 5) that the green to dead ratio of DM appears to be a primary cue of sheep selection, the study reported here included a further evaluation of whether green to dead ratio of herbage influenced selection seasonally. It was hypothesised the animal’s diet selection would change seasonally and result in the consumption of the green vegetative pasture species with the highest nutritive value.

6.2 Materials and methods

6.2.1 Site location and experimental design

Four replicate plots, 0.08 ha (20 m x 40 m), were established within a native grassland in October 2009. The experimental site was located at the EverGraze Central Tablelands Proof Site.

The plots were paired, based upon available forage and similar botanical compositions (plots 1 and 3 and 2 and 4, respectively were paired). The four plots were grazed by two groups of 10 dry Merino ewes (CentrePlus®) at a SR of 125 DSE/ha, during three grazing periods; February 2010, August - September 2010 and February 2011. The order and duration of grazing of plots varied and was based upon FOO. Details of each grazing period, duration of grazing and season are given in Table 6.1.

Refer to Chapter 3, section 3.1 for further information on experiment location and details of site management.

Table 6.1. Detail of grazing periods.

<table>
<thead>
<tr>
<th>Grazing period</th>
<th>Grazing period 1</th>
<th>Grazing period 2</th>
<th>Grazing period 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season</td>
<td>February 2010</td>
<td>August - September 2010</td>
<td>February 2011</td>
</tr>
<tr>
<td></td>
<td>Late summer</td>
<td>Late winter</td>
<td>Late summer</td>
</tr>
<tr>
<td>Grazing exclusion prior to grazing (d)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plots 1 and 3</td>
<td>108</td>
<td>193</td>
<td>158</td>
</tr>
<tr>
<td>Plots 2 and 4</td>
<td>116</td>
<td>179</td>
<td>174</td>
</tr>
<tr>
<td>Dates of grazing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plots 1 and 3</td>
<td>15th – 19th February</td>
<td>31st August – 4th September</td>
<td>9th – 16th February</td>
</tr>
<tr>
<td>Plots 2 and 4</td>
<td>23rd – 28th February</td>
<td>26th – 31st August</td>
<td>21st – 28th February</td>
</tr>
<tr>
<td>Duration of grazing (d)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plots 1 and 3</td>
<td>4</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Plots 2 and 4</td>
<td>5</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

*only plot 4 grazed


6.2.1.1 Climatic data

Climatic data including temperature, relative humidity, rainfall and wind speed was recorded every 15 min at the site (Figure 6.1). The average daily temperature for the first grazing period in February 2010 was 21°C. During the August - September 2010 grazing period the lowest average temperature of 8°C was recorded and during the third grazing period the average daily temperature was 18°C. A total of 48 mm of rainfall was recorded during the second grazing period in August - September 2010. During rainfall events the sheep ceased grazing.

![Figure 6.1. Daily rainfall (columns) and average (blue), maximum (green) and minimum (purple) temperatures during the period February 2010 - February 2011.](image)

6.2.2 Animals

For each grazing period 20 dry, not pregnant Merino ewes were randomly selected from a flock of sheep grazing at the site and thus were familiar with the pasture. The ewes were randomly allocated to one of two groups and all ewes were 3.5 years of age at the first grazing period. The details of ewe age, live weight and BCS for each grazing period are summarised in Table 6.2.
Table 6.2. Ewe age, average live weight (± SE), BCS and period of wool growth at each grazing period.

<table>
<thead>
<tr>
<th>Grazing period</th>
<th>Grazing period 1</th>
<th>Grazing period 2</th>
<th>Grazing period 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ewe age (y)</td>
<td>February 2010</td>
<td>August - September 2010</td>
<td>February 2011</td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>Average live weight (kg)</td>
<td>63 (± 1.8)</td>
<td>61 (± 3.5)</td>
<td>59 (± 2.0)</td>
</tr>
<tr>
<td>BCS</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Period of wool growth (month)</td>
<td>10</td>
<td>3.5</td>
<td>10</td>
</tr>
</tbody>
</table>

6.2.3 Pasture biomass, phenology and species selection

The pasture biomass and composition was assessed using a 0.25 m² (0.5 m x 0.5 m) quadrat prior to and following grazing at 36 permanent points within each plot. The total, green, dead and litter (kg DM/ha) and ground cover (%) were estimated by direct visual assessment (Campbell and Arnold 1973). The estimated values were corrected using the estimated and actual values from calibration quadrats that were sorted into dead and green components. The botanical composition of each quadrat was also estimated by direct visual assessment of the green and dead biomass (kg DM/ha) of all species present. Prior to the commencement of each grazing period calibration quadrats from the area surrounding the grazing plots were estimated, cut, dried and sorted into the green and dead components of each species to determine actual values. Correlation coefficients of 0.9 or greater were achieved and considered acceptable (Campbell and Arnold 1973). The developmental stage of each species was recorded at the initial pasture assessment (prior to grazing) as either; vegetative (V), reproductive (R) and senescent (Sc). Vegetative referred to green actively growing plants prior to flowering, with minimal stem development. Reproductive included plants in flowering and fruit development stage, with more stem growth and senescent referred to plants with dry stems, leaves, seeds and seed pods. The pasture species and developmental stage at each grazing period are listed in Table 6.3.

During each grazing period the pasture was assessed daily and a grazing rating assigned to the green and dead components of each species according to the grazing rating summarised in Chapter 3, section 3.3.1.1 (and Figure 3.3). The development of the grazing rating index is outlined in Appendix A and use of the index was previously examined in Chapter 5.

The index identified the plant species consumed by the animals and the extent to which each species within a quadrat was grazed.
Table 6.3. Major and minor pasture species (and developmental stage) at each grazing period.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Major pasture species</th>
<th>Minor pasture species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grazing period 1</strong>&lt;br&gt;February 2010</td>
<td>Grasses (native – C3)</td>
<td><em>Austrodanthonia</em> spp. (late V)&lt;br&gt;<em>Austrostipa</em> spp. (Sc)&lt;br&gt;<em>Elymus scaber</em> (Sc)&lt;br&gt;<em>Microlaena stipoides</em> (late V)</td>
</tr>
<tr>
<td><strong>Grazing period 2</strong>&lt;br&gt;August - September 2010</td>
<td>Grasses (native – C3)</td>
<td><em>Bothriochloa macra</em> (Sc)</td>
</tr>
<tr>
<td><strong>Grazing period 3</strong>&lt;br&gt;February 2011</td>
<td>Grasses (native – C3)</td>
<td><em>Austrodanthonia</em> spp. (R)&lt;br&gt;<em>Austrostipa</em> spp. (Sc)&lt;br&gt;<em>Elymus scaber</em> (Sc)&lt;br&gt;<em>Microlaena stipoides</em> (late V)</td>
</tr>
</tbody>
</table>
6.2.4 Estimated diet composition
The average daily composition of the diet of each group of ewes was estimated from the pre- and post-grazing biomass together with the daily grazing rating data that identified the plant species consumed by the animals and the extent to which each species within each quadrat was grazed. The contribution of each plant species to the daily intake of the animals within each plot was then calculated as a proportion (%) of the diet consumed each day.

6.2.5 Evaluation of the nutritive value of plant species components
Plant material of the major pasture species was hand-plucked from the plot area prior to grazing and additional samples were collected following daily identification of the pasture species consumed by the animals. The hand-plucked material contained mainly green leaf and stem material with minimal dead forage. Refer to Chapter 3, section 3.3.1.3 for details of methods of sample collection and preparation.

6.2.6 Plant chemical analysis
Proximate analyses of the vegetation samples included; N, ash, DMD, DOMD and ME. Refer to Chapter 3 section 3.3.1.4 for details of analytical procedures.

6.2.7 Statistical analysis
Pre- and post-grazing pasture biomass was analysed using ANOVA (Genstat® 13th edition, Hemel Hempstead United Kingdom) and significant results and relationships were identified when p < 0.05. The relationships between the percentage of herbage consumed and the initial green to dead ratio of the biomass and DOMD of a species were analysed using multiple regression analysis in Genstat.
6.3 Results

6.3.1 Pasture biomass
The average pre- and post-grazing biomass for each grazing period is presented in Table 6.4. For all three grazing periods there was a reduction ($p < 0.001$) in the total and green biomass following grazing. The total litter remained unchanged after the first grazing period (February 2010), was reduced ($p < 0.001$) after the second grazing period (August - September) but increased ($p < 0.001$) following the third grazing period (February 2011). Cover was reduced ($p < 0.05$) following the first grazing period but remained unchanged following the second and third grazing periods.

Table 6.4. Average (± SE) pre- and post-grazing biomass (kg DM/ha) for each grazing period.

<table>
<thead>
<tr>
<th>Grazing period 1 (February 2010)</th>
<th>Grazing period 2 (August - September 2010)</th>
<th>Grazing period 3 (February 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-grazing</td>
<td>Post-grazing</td>
<td>Pre-grazing</td>
</tr>
<tr>
<td>Total</td>
<td>2269 ± 94.1</td>
<td>2183 ± 70.6</td>
</tr>
<tr>
<td>Green</td>
<td>929 ± 49.7</td>
<td>1017 ± 28.1</td>
</tr>
<tr>
<td>Litter</td>
<td>141 ± 9.5</td>
<td>202 ± 13.0</td>
</tr>
<tr>
<td>Cover (%)</td>
<td>93 ± 0.8</td>
<td>92 ± 0.8</td>
</tr>
</tbody>
</table>

A superscript in the post-grazing column indicates a significant difference over time * ($p < 0.05$); ** ($p < 0.001$)

6.3.2 Change in species biomass
The pre- and post-grazing biomass of each species and the proportion the species contributed to the pasture for each grazing period are presented in Table 6.5.

6.3.2.1 February 2010
At the outset the total pasture biomass was 2269 kg DM/ha, consisting of 41% green herbage. The pasture was dominated by *Microlaena stipoides* (46%) and *Austrodanthonia* spp. (22%), with lesser contributions by *Austrostipa* spp. (7%), *Hypochaeris radicata* (6%), *Juncus* spp. (6%), *Elymus scaber* (4%), *Acetosella vulgaris* (1%) and dead *Lolium rigidum* (1%) and *Bothriochloa macra* (< 1%).

Following grazing the biomass of the pasture was reduced to 1510 kg DM/ha, with the biomass of green *M. stipoides*, *Austrodanthonia* and *H. radicata* being reduced ($p < 0.001$). The biomass of dead *M. stipoides*, *Austrodanthonia* spp. and *L. rigidum* and the green biomass of *E. scaber*, *Austrostipa* spp. and *A. vulgaris* was also reduced ($p < 0.05$).
6.3.2.2 August - September 2010

Prior to grazing the pasture biomass was 2183 kg DM/ha and consisted of 47% green herbage. The pasture consisted of *M. stipoides* (42%), *Austrodanthonia* spp. (23%), *E. scaber* (11%), *H. radicata* (6%), *L. rigidum* (5%), *Austrostipa* spp. (5%), *Juncus* spp. (5%), *Poa bulbosa* (2%), *Asphodelus fistulosus* (1%), *Holcus lanatus* (< 1%), *A. vulgaris* (< 1%) and dead *Bothriochloa macra* (< 1%). Subsequent to grazing the herbage mass declined to 1210 kg DM/ha with the biomass of green *M. stipoides*, *Austrodanthonia* spp., *E. scaber* and green and dead *H. radicata* being reduced (p < 0.001). The biomass of green *P. bulbosa*, *A. fistulosus*, *A. vulgaris* and the dead biomass of *M. stipoides* *Austrodanthonia* spp. and *E. scaber* were also reduced (p < 0.05) post-grazing.

6.3.2.3 February 2011

Initially the pasture biomass was 4429 kg DM/ha, with green forage accounting for 36% of the total pasture that was comprised of; *M. stipoides* (64%), *H. lanatus* (14%), *H. radicata* (10%), *Austrodanthonia* spp. (4%), *Juncus* spp. (2%), *E. scaber* (1%), *A. vulgaris* (1%), *L. rigidum* (1%) and *Austrostipa* spp. (< 1%). Post-grazing the pasture biomass was reduced to 3532 kg DM/ha and green herbage mass of *M. stipoides* and *H. radicata* was reduced (p < 0.001) as was the green herbage mass of *H. lanatus* and *A. vulgaris* (p < 0.05).

6.3.3 Species selection over time

6.3.3.1 February 2010

The major pasture species the animals selected over time (as a proportion of the animal’s diet) are presented in Figure 6.2. The animals initially selected a diet comprised of green vegetative material dominated by green *M. stipoides* (62%); *Austrodanthonia* spp. (18%) and *H. radicata* (14%) that respectively, only accounted for 26%; 7% and 3% of the available pasture. Thus the ewes consumed green *M. stipoides*, *Austrodanthonia* spp. and *H. radicata* in proportions 2.4, 2.6 and 4.7 times the availability of the species components within the pasture, respectively. The dead component of the three pasture species accounted for 43% of the pasture and disappeared at an increasing rate over time with grazing. Disappearance was largely due to grazing, but losses were also due to other processes, such as trampling and damage during the grazing process. On day 1 of grazing dead forage contributed only 1.4% of the total disappearance of DM. However, by the second day of grazing the dead
components of the pasture accounted for 28% of the disappearance. By days 4 and 5 of grazing approximately 52% of the DM disappearance was dead forage. On day 3 of grazing the animals’ intake of green *M. stipoides*, *Austrodanthonia* spp. and *H. radicata* declined as the intake of the dead component of these species increased as did the intake of green *Austrostipa* spp. and *E. scaber*. The intake of green and dead *M. stipoides*, *Austrodanthonia* spp. and *H. radicata* and green *Austrostipa* spp. and *E. scaber* remained constant for days 4 and 5 of grazing as the animals continued to select green *Austrodanthonia* spp., *Austrostipa* spp., *E. scaber* and *H. radicata* and consumed these species in quantities 2.5 times their availability within the pasture. More than 10 small green and dead uprooted *Austrostipa* spp. plants were found lying in the pasture throughout the grazing period.

The animals were observed to initially graze the green leafy material of *M. stipoides* and *Austrodanthonia* spp. and the crown of the *H. radicata* plants. Over time the animals continued to select the green components of these species and consumed green stem and leaf material of the grasses and progressively grazed the remaining green leaf of previously grazed *H. radicata* rosettes. Similarly, the animals consumed the green leaf material of *Austrostipa* spp. and *E. scaber* and avoided the senescent material of these species. The animals did not consume the dead *L. rigidum* spp. present as standing dead material and the decline (p < 0.05) in the biomass of this species was not a consequence of the animals ingesting the forage, but rather the brittle standing dead material being broken and left as litter.
Table 6.5. Average (± SE) pre- and post-grazing biomass (kg DM/ha) and the proportion the species contributed to the pasture for each grazing period.

<table>
<thead>
<tr>
<th>Native grasses (C3)</th>
<th>Grazing period 1 (February 2010)</th>
<th></th>
<th>Grazing period 2 (August - September 2010)</th>
<th></th>
<th>Grazing period 3 (February 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Herbage mass (kg DM/ha) (%)</td>
<td>Herbage mass (kg DM/ha) (%)</td>
<td>Herbage mass (kg DM/ha) (%)</td>
<td>Herbage mass (kg DM/ha) (%)</td>
<td></td>
</tr>
<tr>
<td><strong>Acetosella vulgaris</strong></td>
<td>11 ± 3.4 (0.5) 4 ± 1.0* (0.1)</td>
<td>1 ± 0.4 (0.1) 1 ± 0.3 (0.1)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
</tr>
<tr>
<td><strong>Asphodelus fistulosus</strong></td>
<td>3 ± 0.8 (0.2) 1 ± 0.0* (0.1)</td>
<td>1.5 ± 0.4 (0.1) 0 ± 0.1 (0.1)</td>
<td>1.5 ± 0.4 (0.1) 0 ± 0.1 (0.1)</td>
<td>1.5 ± 0.4 (0.1) 0 ± 0.1 (0.1)</td>
<td>1.5 ± 0.4 (0.1) 0 ± 0.1 (0.1)</td>
</tr>
<tr>
<td><strong>Austrodanthonia</strong></td>
<td>579 ± 50.3 (25.5) 250 ± 23.6** (16.6)</td>
<td>365 ± 29.8 (18.4) 219 ± 19.1** (19.8)</td>
<td>1111 ± 73.4 (25.1) 689 ± 59.2** (19.5)</td>
<td>1704 ± 133.0 (38.5) 1595 ± 127.0 (45.2)</td>
<td>58 ± 39.0 (1.3) 27 ± 14.5 (0.8)</td>
</tr>
<tr>
<td><strong>Hypochaeris radicata</strong></td>
<td>475 ± 37.6 (20.9) 370 ± 32.3* (24.5)</td>
<td>460 ± 42.4 (23.2) 307 ± 28.3* (27.7)</td>
<td>134 ± 53.4 (3.0) 124 ± 46.4 (3.5)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>4 ± 4.2 (0.1) 4 ± 4.2 (0.1)</td>
</tr>
<tr>
<td><strong>Microlaena stipoides</strong></td>
<td>163 ± 13.9 (7.2) 62 ± 5.8** (4.1)</td>
<td>197 ± 21.7 (9.9) 124 ± 14.4* (11.2)</td>
<td>3 ± 2.8 (0.1) 3 ± 2.8 (0.1)</td>
<td>3 ± 2.8 (0.1) 3 ± 2.8 (0.1)</td>
<td>3 ± 2.8 (0.1) 3 ± 2.8 (0.1)</td>
</tr>
<tr>
<td><strong>Bothriochloa macra</strong></td>
<td>2 ± 1.5 (0.1) 1 ± 1.0 (0.1)</td>
<td>5 ± 5.4 (0.3) 4 ± 4.2 (0.4)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
</tr>
<tr>
<td><strong>Lolium rigidum</strong></td>
<td>16 ± 4.5 (0.7) 5 ± 2.0* (0.3)</td>
<td>21 ± 4.9 (1.1) 10 ± 2.1 (0.9)</td>
<td>21 ± 8.1 (0.5) 8 ± 4.2 (0.2)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
</tr>
<tr>
<td><strong>Poa bulbosa</strong></td>
<td>16 ± 4.5 (0.7) 5 ± 2.0* (0.3)</td>
<td>21 ± 4.9 (1.1) 10 ± 2.1 (0.9)</td>
<td>21 ± 8.1 (0.5) 8 ± 4.2 (0.2)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
</tr>
<tr>
<td><strong>Holcus lanatus</strong></td>
<td>3 ± 3.4 (1.5) 12 ± 5.0* (0.8)</td>
<td>4 ± 1.0 (0.2) 1 ± 0.7* (0.1)</td>
<td>6 ± 1.0 (0.2) 7 ± 0.9* (0.1)</td>
<td>6 ± 1.0 (0.2) 7 ± 0.9* (0.1)</td>
<td>6 ± 1.0 (0.2) 7 ± 0.9* (0.1)</td>
</tr>
<tr>
<td><strong>Vaccinium arbuscula</strong></td>
<td>3 ± 0.8 (0.2) 1 ± 0.3 (0.1)</td>
<td>1 ± 0.4 (0.1) 1 ± 0.3 (0.1)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
</tr>
<tr>
<td><strong>Juncus spp.</strong></td>
<td>33 ± 16.1 (1.5) 30 ± 14.4 (2.0)</td>
<td>23 ± 10.7 (1.2) 18 ± 8.1 (1.7)</td>
<td>21 ± 8.0 (0.5) 21 ± 8.0 (0.6)</td>
<td>21 ± 8.0 (0.5) 21 ± 8.0 (0.6)</td>
<td>21 ± 8.0 (0.5) 21 ± 8.0 (0.6)</td>
</tr>
<tr>
<td><strong>Asphodelus fistulosus</strong></td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>13 ± 3.1 (0.7) 6 ± 1.4* (0.5)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
</tr>
<tr>
<td><strong>Forbs</strong></td>
<td>1 ± 0.4 (0.1) 1 ± 0.3 (0.1)</td>
<td>1 ± 0.4 (0.1) 1 ± 0.3 (0.1)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0) 0 ± 0.0 (0.0)</td>
</tr>
</tbody>
</table>

A superscript in the post-grazing column indicates a significant difference over time * (p <0.05); ** (p <0.001)
Figure 6.2. Average intake (as a proportion of the diet) of the major pasture species over time. February 2010. Green *M. stipoides* (green); green *Austrodanthonia* spp. (red); green *E. scaber* (orange); green *Austrostipa* spp. (blue); green *H. radicata* (khaki); dead *M. stipoides* (purple); dead *Austrodanthonia* spp. (pink)

6.3.3.2 August - September 2010

As shown in Figure 6.3, on day 1 of grazing the ewes selected a diet of green *Austrodanthonia* spp. (23%), *H. radicata* (20%), *E. scaber* (16%) and *L. rigidum* (11%). These species accounted for 13%, 5%, 6% and 4% of the available pasture and were consumed in proportions 1.8, 4.0, 2.7 and 2.8 times greater than the availability of the green of these species within the pasture, respectively. Green *M. stipoides* was also consumed by the animals and whilst it represented 15% of the animals’ diet, it comprised 18% of the available pasture. The dead components of pasture represented 10.7% of the animals’ diet on day 1, increasing to 28% by the second day of grazing. The animals’ intake of dead forage increased over time and peaked at 48% of the diet on day 4 before declining to 43% on day 5. On the second day of grazing the proportion of green *H. radicata*, *E. scaber* and *L. rigidum* in the diet declined and continued to decline over the remainder of the grazing period, whilst the proportion of green and dead *Austrodanthonia* spp. and *M. stipoides* increased from the previous day. From day 3 onwards the intake of green *Austrodanthonia* spp. declined as intake of dead *Austrodanthonia* spp. and green and dead *M. stipoides* increased over time and by day 4
of grazing the dead component contributed a greater proportion to the diet than the green component of these species.

Initially, the animals selected the green vegetative material of *Austrodanthonia* spp., *E. scaber* and *L. rigidum* and the crown of the *H. radicata* before re-grazing the plants over time and consuming the stem material of the grass species. Similar to the previous grazing period, more than 15 small green and dead uprooted *Austrostipa* spp. plants were found lying in the pasture throughout the study period.

![Figure 6.3](image)

**Figure 6.3.** Average intake (as a proportion of the diet) of the major pasture species over time. August - September 2010. Green *M. stipoides* (green); green *Austrodanthonia* spp. (red); green *E. scaber* (orange); green *L. rigidum* (grey); green *H. radicata* (khaki); dead *M. stipoides* (purple); dead *Austrodanthonia* spp. (pink)

### 6.3.3.3 February 2011

The animals initially consumed a diet dominated by green *M. stipoides* (51%) and included *H. radicata* (19%), *H. lanatus* (8%) and *Austrodanthonia* spp. (4%), as shown in Figure 6.4. These species represented approximately 25%, 3%, 6% and 1%, respectively, of the available pasture biomass and thus the animals consumed these forages in proportions 2, 6.3, 1.3 and 4 times the availability of these species within the pasture, respectively. On the first day of grazing the diet also included approximately 7.7% dead material. Over subsequent days, intake of green *M. stipoides, H. radicata*
and H. lanatus declined as the intake of green and dead M. stipoides and dead Austrodanthonia spp. increased.

The disappearance of dead forage increased on day 2, at which time it accounted for approximately 27% of the diet and by day 5 accounted for 54% of the diet. Dead Austrodanthonia spp. initially represented 3% of the available pasture biomass whereas green Austrodanthonia spp. accounted for approximately 1% of the pasture with the exception of the first day of grazing. Throughout the grazing period dead Austrodanthonia spp. was consumed in greater quantities than the green of the species that was in a reproductive phenological stage. By day 4 of grazing the dead and green components of M. stipoides were consumed in similar quantities; however, from day 4 onwards the dead was consumed in greater quantities than the green component. The animals maintained their intake of the green components of the species over time by grazing and progressively re-grazing the plants within the pasture. During the grazing period more than 10 small green and dead freshly uprooted Austrostipa spp. plants were found lying in the pasture.

**Figure 6.4.** Average intake (as a proportion of the diet) of the major pasture species over time. February 2011. Green M. stipoides (green); green Austrodanthonia spp. (red); green H. radicata (khaki); green H. lanatus (gold); dead M. stipoides (purple); dead Austrodanthonia spp. (pink)
6.3.4 Vegetation quality analysis

The quality of the available average green pasture for each grazing period is shown in Table 6.6 and the quality of the pasture species selected by the animals during each grazing period is shown in Table 6.7. The N content of the average available green pasture was higher (p < 0.05) in the first grazing period (February 2010) compared to the second grazing period (August - September 2010). The DOMD and ME of the average green pasture were similar for all three grazing periods.

6.3.4.1 February 2010

The pasture species initially selected by the animals were *M. stipoides*, *Austrodanthonia* spp., *H. radicata* and *A. vulgaris* and all of these species had a greater N content, digestibility and ME than the average available green pasture. Of the hand-plucked samples, *A. vulgaris* had the highest N and ME content and the greatest digestibility. Of the grasses *M. stipoides*, in a late vegetative stage of development was higher in N, DOMD and ME than *Austrodanthonia* spp. in the same physiological stage.

Table 6.6. Nitrogen content, DOMD and ME of the average available green pasture species at each grazing period (average ± SE)

<table>
<thead>
<tr>
<th>Grazing period</th>
<th>N (%)</th>
<th>DOMD (%)</th>
<th>ME (MJ/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. February 2010</td>
<td>2.6* ± 0.17</td>
<td>53 ± 1.9</td>
<td>7.7 ± 0.38</td>
</tr>
<tr>
<td>2. August - September 2010</td>
<td>1.9* ± 0.17</td>
<td>54 ± 4.0</td>
<td>8.0 ± 0.80</td>
</tr>
<tr>
<td>3. February 2011</td>
<td>2.1 ± 0.15</td>
<td>53 ± 1.2</td>
<td>7.8 ± 0.22</td>
</tr>
</tbody>
</table>

A superscript of * indicates a significant difference over time (p < 0.05) between values in the same column.

6.3.4.2 August - September 2010

At the outset of grazing the animals selected green *Austrodanthonia* spp., *H. radicata*, *E. scaber*, *L. rigidum* and *M. stipoides*. The quality of the hand-plucked green *Austrodanthonia* spp. sample was lower than the average available green pasture during the grazing period (1.9% N, 54% DOMD, 8 MJ ME/kg DM). Green *H. radicata* had the highest N and ME contents and digestibility whilst *H. lanatus* and *L. rigidum* were similar to in terms of DOMD and ME. *M. stipoides* in a reproductive physiological state was of greater quality than *Austrodanthonia* spp. in a similar stage of development.
Table 6.7. Average N content, DOMD and ME of green pasture species components at each grazing period.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Component</th>
<th>Grazing period 1 February 2010</th>
<th>Grazing period 2 August-September 2010</th>
<th>Grazing period 3 February 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N (%)</td>
<td>DOMD (%)</td>
<td>ME (MJ/kg DM)</td>
</tr>
<tr>
<td>Native grasses (C3)</td>
<td><em>Microlaena stipoides</em></td>
<td>3.7</td>
<td>63</td>
<td>9.8</td>
</tr>
<tr>
<td></td>
<td><em>Austrodanthonia spp.</em></td>
<td>3.3</td>
<td>60</td>
<td>9.2</td>
</tr>
<tr>
<td>Introduced grasses (C3)</td>
<td><em>Lolium rigidum</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td><em>Holcus lanatus</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td><em>Hypochaeris radicata</em></td>
<td>3.6</td>
<td>69</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td><em>Acetosella vulgaris</em></td>
<td>3.7</td>
<td>70</td>
<td>11.1</td>
</tr>
</tbody>
</table>

6.3.4.3 February 2011

During the grazing period the biomass of green *M. stipoides, H. radicata*, (p < 0.001) and *H. lanatus* and *A. vulgaris* (p < 0.05) was reduced due to preferential grazing. All of these species were of greater N content, digestibility and ME than the average available green pasture. The analysed sample of green *Austrodanthonia* spp. in a reproductive stage of development was of similar digestibility and ME to the average green available pasture, but had a higher N content than the average available green pasture.

6.3.5 Initial pasture composition and diet selection

The species selectivity of the animals was further investigated in relation to the green to dead ratio of the pasture species as well as the quality of the species for each study period.

6.3.5.1. February 2010

There was no relationship (p > 0.05) between the green biomass of a species or initial green to dead ratio of the pasture (Figure 6.5) and high levels of consumption of green herbage by the animals. However, for *E. scaber* (p < 0.05) and *Austrostipa* spp. (p > 0.05) that were senescent, an upward trend was observed between high consumption of green herbage and high initial green to dead ratio of a species. A positive linear relationship (p < 0.001) was identified between the DOMD of the major species selected by the animals that were in a vegetative state (*M. stipoides, Austrodanthonia* spp. and *H. radicata*) and the percentage of green herbage consumed by the animals (R^2 = 0.68) (Figure 6.6).
Figure 6.5. Initial green to dead ratio of the DM of the major species and the percentage of green herbage consumed by the animals. February 2010. Green *M. stipoides* (green); green *Austrodanthonia* spp. (red); green *E. scaber* (orange); green *Austrostipa* spp. (blue); green *L. rigidum* (grey); green *H. radicata* (khaki). (p > 0.05)

6.3.5.2 August - September 2010

There was no relationship (p > 0.05) between the green biomass of a species and high levels of green herbage consumption. A positive exponential relationship (p < 0.001) between high levels of initial green to dead ratio of a pasture and high levels of green herbage consumption (%) by the animals was established for the second grazing period in August - September 2010 with an adjusted $R^2$ value of 0.62 (Figure 6.7). The relationship was influenced by green vegetative *H. radicata* and *L. rigidum* that recorded initial green to dead ratio of greater than 3. The relationship between the consumption of the native pasture species (*M. stipoides*, *Austrodanthonia* spp., *E. scaber* and *Austrostipa* spp.) with a maximum initial green to dead ratio of < 2, was analysed. A positive linear relationship (p < 0.001) was evident between high levels of initial green to dead ratio of the species and high levels of consumption of the forage by the animals ($R^2 = 0.57$). A weaker, but significant relationship (p < 0.05) was identified between the DOMD of the initial pasture species and the percentage of green herbage consumed by the animals ($R^2 = 0.23$) (Figure 6.8). The relationship was influenced by *Austrostipa* spp. (p < 0.05) that was of low quality and in a reproductive stage of development.
Figure 6.6. Linear relationship between the DOMD of the major species selected by grazing sheep and the percentage of green herbage consumed by the animals. February 2010. Green *M. stipoides* (green); green *Austrodanthonia* spp. (red); green *H. radicata* (khaki). (p < 0.001; $R^2 = 0.68$)

Figure 6.7. Relationship between initial green to dead ratio of the DM of the major pasture species and the percentage of green herbage consumed. August - September 2010. Green *M. stipoides* (green); green *Austrodanthonia* spp. (red); green *E. scaber* (orange); green *Austrostipa* spp. (blue); green *L. rigidum* (grey); green *H. radicata* (khaki). (p < 0.001; $R^2 = 0.62$)
6.3.5.3 February 2011

There was no relationship (p > 0.05) between the green biomass of a species or initial green to dead ratio of the pasture (Figure 6.9) and high levels of consumption of green herbage by the animals. Similar to February 2010, the relationship was influenced by *Austrostipa* spp. (p > 0.05) and an upward trend was observed between high consumption of green herbage and high initial green to dead ratio of a species. A positive linear relationship (p < 0.05) was identified between the DOMD of the major species selected by the animals (green *M. stipoides*, *Austrodanthonia* spp. and *H. radicata*) that were in a vegetative state and the percentage of green herbage consumed by the animals ($R^2 = 0.63$) (Figure 6.10).

![Figure 6.8. Relationship between initial DOMD of the major pasture species and the percentage of green herbage consumed. August - September 2010. Green *M. stipoides* (green); green *Austrodanthonia* spp. (red); green *E. scaber* (orange); green *L. rigidum* (grey); green *H. radicata* (khaki); green *Austrostipa* spp. (blue). (p < 0.05; $R^2 = 0.23$)]
Figure 6.9. Initial green to dead ratio of the DM of the major species and the percentage of green herbage consumed by the animals. February 2011. Green *M. stipoides* (green); green *Austrodanthonia* spp. (red); green *Austrostipa* spp. (blue); green *L. rigidum* (grey); green *H. radicata* (khaki). (p > 0.05)

Figure 6.10. Linear relationship between the DOMD of the major species selected by grazing sheep and the percentage of green herbage consumed by the animals. February 2011. Green *M. stipoides* (green); green *Austrodanthonia* spp. (red); green *H. radicata* (khaki). (p < 0.05; $R^2 = 0.63$)
6.3.5.4 Pasture composition and diet selection over time

The initial green to dead and the DOMD of the major pasture species relative to the percentage of green forage consumed by the animals was analysed for all of the grazing periods. A multiple regression analysis including time, species, physiological stage, green biomass, green to dead ratio of DM and DOMD was used to identify the factors that influenced the consumption of each species. The results were confounded by changes in the pasture species over time including the physiological stage of development, the resulting green to dead ratio of DM and the low quality species *E. scaber* and *Austrostipa* spp. A linear relationship ($p < 0.001$) between the DOMD of the major species (*M. stipoides*, *Austrodanthonia* spp., *H. radicata* and *L. rigidum*) and the proportion of green herbage consumed over time was identified ($R^2 = 0.60$), where increasing proportions of green herbage of a species was consumed in response to higher DOMD of a species (Figure 6.11). No relationship ($p > 0.05$) was identified between the green to dead ratio of DM, green biomass and physiological stage of development over time.

![Figure 6.11](image)

*Figure 6.11.* Linear relationship between the DOMD of the major species selected by grazing sheep and the percentage of green herbage consumed by the animals over time. Green *M. stipoides* (green); green *Austrodanthonia* spp. (red); green *H. radicata* (khaki). ($p < 0.001$; $R^2 = 0.60$)
6.4 Discussion
In this study the diet composition and intake of two groups of dry, not pregnant ewes grazing small plots within a native grassland was successfully estimated and the animals consistently selected the vegetative material from within the pasture. The results of this study support the view that sheep were primarily selecting herbage based upon the green to dead DM ratio of a species, rather than nutrient content of a species during late winter - early spring (in August - September 2010) when the pasture contained the greatest proportion of green forage (≈ 50%). In contrast, during summer, with lower proportions of green forage no relationship (p > 0.05) was identified between the green to dead DM ratio of a species. However, during this season the animals consistently selected the vegetative green forage from within the pasture and consumed greater quantities of a species as DOMD increased. The study design reflected the timing and management of the RG system at the site and the diet selection of sheep varied seasonally and was influenced by the stage of development of plant species.

Following all three periods of grazing the total and green biomass within the pasture was significantly reduced. The initial and remaining biomass and sward height pre- and post-grazing for each grazing period was substantially greater than 550 kg DM/ha which, according to Hamilton et al. (1973), is the biomass availability where the selectivity of grazing sheep becomes limited. Thus, there was sufficient biomass available at all times for the sheep to exhibit selective grazing. The methods used to assess livestock selection and consumption detected significant patterns in what the animals ate, in response to seasonal changes in the vegetation and the available pasture over time. These methods were intensive and sensitive enough to identify species selection over time and identify cues that the sheep seemed to be responding to in August - September (late winter - early spring). These results suggest that more invasive techniques of oesophageal and/or rumen fistulation are not mandatory for investigating consumption patterns of grazing animals.

6.4.1 February 2010
During the first grazing period, in late summer when the pasture comprised of 41% green forage, the N content of the average available green pasture was higher than that of the pasture at the other grazing periods, although the ME and DOMD were similar.

On the first day of grazing when selectivity would presumably be highest, the diet was dominated by green M. stipoides, Austrodanthonia spp. and H. radicata and the sheep
consumed these species in proportions substantially greater than their availability within the pasture. The green forage of these species was substantially higher in N, ME and DOMD than the average green pasture. On the first day of grazing the dead components of these species represented 43% of the available pasture; however, they were avoided by the animals and only accounted for 1.4% of the selected diet. Animals clearly select green forage primarily. The disappearance of the dead forage of these species increased to 28% of the diet by day 2 as the green herbage of these species declined from 94% to 67% of the diet and continued to decline over subsequent days. The substantial increase in the disappearance of dead plant material from day 1 to day 2 was unexpected and may in part be a result of the visual estimation method having overestimated the total DM reduction of the dead component of the pasture, similar to other observations using the technique in the same pasture (Badgery, unpub. data). By the third day of grazing the disappearance of dead *Austrodanthonia* spp. was greater than the green forage of the species and the animal’s intake of green *E. scaber* and *Austrostipa* spp. increased. The active selection of these species by the ewes may be a consequence of declining availability of the preferred green *M. stipoides* and *Austrodanthonia* spp. together with the animals’ diminishing ability to select only green forage of these species and the increased ‘apparenacy’ of green *E. scaber* and *Austrostipa* spp. within the pasture. The selection of the green fractions of these species was notable as the majority of the forage of these species was senescent material. The animal’s selection of the green fractions of these lower quality species is likely to be associated with a severe decline in the quality of the animal’s diet and the consumption of these species within the pasture may be a cue for farmers managing stock within RG systems of discerning the timing of rotations.

The animals displayed a high degree of selectivity as evidenced by the significant consumption of green *H. radicata* (p < 0.001) and *A. vulgaris* (p < 0.05) with high N content and DOMD. The ewes consumed green *H. radicata* in proportions 4.7 times its availability in the pasture and selected green *A. vulgaris* that accounted for only 0.1% of the initial pasture.

The selection of the green component of the major pasture species was related to the DOMD of the species (p < 0.001; R² = 0.68) whereby a greater proportion of green herbage of a species was consumed as the DOMD of the species increased. However, as animals cannot perceive nutrients per se (Arnold, 1981) the primary cue of the animal’s
selection and consumption of green forage was unclear. An upward trend in the initial green to dead ratio of a species was observed between a high initial green to dead ratio of a species and a high level of the consumption of the green herbage of the species when the lower quality and lower proportion species of *E. scaber* and *Austrostipa* spp. were not included.

The grazing rating assessments together with the BOTANAL assessments were sensitive enough to distinguish that the reduction (p < 0.05) in the biomass of dead *L. rigidum* was not due to the animals consuming the forage, but rather the brittle stems being broken and left as litter. Furthermore, the uprooted, small green and dead *Austrostipa* spp. plants observed during the study were identified and not included as consumed forage. The removal of *Austrostipa* spp. observed during all three study periods was presumably the result of the animals dropping or spitting out the plants during grazing and was similar to the removal of cape weed *Arctotheca calendula* observed by Broom and Arnold (1986) in sheep grazing a pasture predominated by *L. rigidum* and *Trifolium subterraneum* that included *Arctotheca calendula* and *Vulpia myuros*. The authors suggested the uprooting of these non-preferred plants may have the effect of improving the pasture by favouring the growth of the preferred species.

The observed initial grazing and repeated defoliation of grass plants and *H. radicata* rosettes over the period of grazing was similar to previous observations (Briske and Stuth 1982; Pierson and Scarneccia 1987; Jensen *et al.* 1990) of grazing ruminants. However, the observed repeated defoliation within this study was greater than the other studies, which was presumably a consequence of the high SR of the animals within this study. From a diet quality perspective, the initial bite consumed of a plant will be more nutritious than subsequent bites from the same plant (Norton 2003). Thus it is suggested that the recorded intake of *E. scaber* and *Austrostipa* spp. by the animals on the third day of grazing may in part be related to the increased ‘apparency’ of the plants within the pasture, the animals’ increasing consumption of dead forage and the small area the animals were restricted to for the study.

### 6.4.2 August - September 2010

The available pasture at the commencement of the second grazing period in late winter provided the lowest biomass of the three grazing periods, although it contained the highest proportion of green forage, accounting for 47% of the total biomass. The average available green pasture had the lowest N content, which was significantly lower
than the N content of average available green pasture in the previous grazing period. 
The lower N content of these plants coincides with the period when available soil N is 
lowest (Badgery, unpub. data) and may also be a consequence of the limited pasture 
growth over the winter periods due to low temperatures limiting leaf growth and frost 
damage, both of which meant the leaf material was mature.

Similar to the diet selection observed in late summer the animals displayed strong 
selection for the green forage of particular species and avidly selected green *H. radicata* 
and consumed the forb in proportions 4.4 times its availability within the pasture. The 
animals’ high degree of selectivity was also demonstrated by the significant reduction in 
the biomass of green *A. fistulosus* and *A. vulgaris* (*p < 0.05*) that represented 0.7 and 
0.2% of the initial pasture, respectively.

On the first day of grazing during this late winter period the animals consumed a greater 
number of plant species than during the previous period and consumed green 
*Austrodanthonia* spp., *E. scaber*, *L. rigidum* and *M. stipoides*. The strong selection of 
green *Austrodanthonia* spp., *E. scaber* and *L. rigidum* together with *H. radicata* by the 
animals was evidenced by the contribution of the green of these species in proportions 
greater than they were present within the pasture. In contrast to the previous grazing 
period, green *M. stipoides* was initially included in the diet in a proportion less than its 
availability within the pasture.

The selected diet on the first day of grazing during this period included approximately 
11% dead forage material. By day 2 consumption of dead forage had increased and 
accounted for the same proportion (28%) of the diet as that recorded in late summer. 
The higher level of dead material within the diet on the first day of grazing may be a 
result of the animals being less selective in their grazing in response to reduced grazing 
time as a consequence of a reduction in daylight hours during winter and rainfall 
(Arnold 1982; Champion *et al.* 1994).

The animals’ intake of green *Austrodanthonia* spp. and *M. stipoides* increased on day 2, 
as did the intake of the dead component of these species. In contrast, intake of green *H. 
radicata, E. scaber* and *L. rigidum* declined and continued to decline from the second 
day of grazing onwards. An exception to this was green *E. scaber*, as its intake 
increased marginally on day 4 and was maintained at the same proportion on day 5. By 
the third day of grazing consumption of green *Austrodanthonia* spp. declined whilst 
intake of the dead component of the species increased and continued to increase to the
extent that by day 4 and day 5, the animals consumed a greater proportion of dead than green Austrodanthonia spp. Intake of M. stipoides increased over the duration of the grazing period. By day 3 the animals were consuming more dead than green herbage of the species and by day 5 consumed these components in similar proportions. The increased consumption of this species may be a consequence of the spatial arrangement of the plants within the pasture that lead to the ‘apparency’ and accessibility of the species increasing over time in response to the declining biomass of the pasture.

The grazing rating assessments together with the pasture biomass assessments identified that the significant reduction in the biomass of dead H. radicata (p < 0.001) as well as dead E. scaber and Poa bulbosa (p < 0.05) was not a result of the animals consuming the pasture component. As the initial standing dead biomass of the species was left as litter as the animals presumably broke the brittle stems of the plants intentionally or unintentionally as they grazed. Similar to the previous grazing period the uprooting of small, green and dead Austrostipa spp. plants was observed.

The selection of green Austrodanthonia spp. by the animals is noteworthy, given that its N and ME contents were less than that of the average available green pasture. The low quality of this species may be underestimated as the wet chemistry and in vitro analysis of hand-plucked pasture samples that may not be representative of the exact components of a species consumed by the grazing animals (Gordon 1995; Ben Salem and Papachristou 2005). The animals’ consumption of green Austrodanthonia spp. may in part be explained by the spatial arrangement of the species and species components within the pasture and the relationship between the initial ratio of green to dead forage and consumption of green forage by the animals.

The positive exponential relationship between the initial green to dead ratio of the major pasture species and the consumption of green forage by the animals highlights the strong selection by the animals of green vegetative forage that was present as green H. radicata and L. rigidum. The positive linear relationship between the four major native grass species and the percentage of green forage consumed indicates plants with a greater proportion of green to dead forage will be consumed to a greater degree by the animals than plants with a lower ratio of green to dead forage. This relationship was only identified in late winter (August – September) with the greatest percentage of green forage of the grazing periods and may be the means by which the animals discern the higher quality species from within the pasture. Together these results highlight the
influence of the developmental growth stage of a species and also the spatial arrangement of plant components within a pasture on the selection of grazing animals and furthermore indicate selection of grazing animals is modified by the relative proportions of different plant species or components and their distribution in space (Hodgson 1982).

6.4.3 February 2011
The available biomass at the start of the third grazing period, in late summer, was the highest of all the study periods but contained the lowest proportion of green forage (36%). The average green pasture contained a greater quantity of N than the previous grazing period in late winter, but a lower quantity than the average green pasture of the first grazing period in February 2010. The pasture quality of the green component of the species tested was comparable to the first grazing period conducted at the same time the year prior. Similar to the February of 2010 the pasture was dominated by *M. stipoides* (64% of the available biomass) that represented a greater proportion of the pasture than at the same time the previous year. In comparison to the pasture in February 2010, there was a greater proportion of *H. lanatus* (13.6% vs. 0 %) and *H. radicata* (10.3% vs. 5.7 %) and substantially less *Austrodanthonia* spp. (4.3% vs. 22.1 %) and less *E. scaber*, *Austrostipa* spp. and *Juncus* spp.

The animals displayed strong selection for the green vegetative material of the pasture similar to the previous study periods and notably selected green *H. radicata* in proportions 6.3 times its availability within the pasture. The spatial arrangement of the green and dead components of *M. stipoides* and *Austrodanthonia* spp. was in an intimate mixture, where the green and dead leaf and stem material of these species was intermixed throughout the vertical plane of the pasture. The arrangement of the forage components may have impeded the high degree of selectivity that sheep are generally able to exert within a pasture to select preferred plant parts (Hodgson 1982).

Intake of dead forage over time was similar to the previous grazing periods and the intake of dead forage on the second day was the same for all three grazing periods (27-28%).

The same strong linear relationship (p < 0.05; R² = 0.68) identified in February 2010 was observed between greater proportions of green herbage consumption and increasing DOMD of a species. The selection of these species was not found to be associated with
the green biomass of a species or the initial green to dead ratio of the DM. The underlying mechanisms of the animal’s selection are not fully understood and may be a result of the animal’s previous grazing experience (Arnold 1964; Arnold and Maller 1977; Ortega-Reyes and Provenza 1993; Olson et al. 1996) within the pasture and/or the animal’s preference for younger plant material with readily digestible energy (Hanley 1982; Provenza 1995) that may be associated with plant height (Bailey et al. 1996).

Strong selection by the sheep was evident throughout all grazing periods and in February 2011 the animals notably reduced (p < 0.05) the green biomass of *A. vulgaris*, which accounted for only 0.4% of the total pasture biomass. The highly favoured pasture species were high in N, ME and DOMD and were presumably highly palatable and support the concept that the selectivity of grazing ruminants is driven by the consumption of a diet that best meets the animal’s nutrient requirements.

### 6.4.4 Seasonal diet selection of grazing sheep

The three grazing periods allowed the evaluation of the seasonal and annual diet selection of animals grazing small plots of native pasture within the Central Tablelands of NSW. The study area was dominated by the native, perennial grasses *M. stipoides* and *Austrodanthonia* spp. and these grasses accounted for the majority of the diet selected during each of the grazing periods. The animals consistently selected green forage and displayed strong selection and preference for green vegetative material within the pasture. The sheep avidly selected green *H. radicata* and consumed the forb in proportions 4.0 – 6.6 times its availability within the pasture. The selection of the forb observed in this study was less than that observed by Leigh and Holgate (1978) in sheep grazing a *Themeda australis* dominate grassland. However, in their study the forb contributed only negligible proportions (approximately 1%) to the sheep’s diet after the first day of grazing, whilst in this study the sheep were observed to characteristically consume the crown of the plants and re-graze the remaining herbage of the plant over subsequent days and by doing so, maintained their intake of the forb in greater proportions over the duration of each grazing period.

The pattern of grazing individual plants by the animals was consistent for the three grazing periods whereby the ewes initially grazed the green leaf material of preferred species and subsequently re-grazed the remaining forage of the plants over time, similar to previous studies (Briske and Stuth 1982; Pierson and Scarnecchia 1987; Jensen et al. 1990). The repeated defoliation of plants by the animals is presumably associated
with a decline in diet quality (Norton 2003) as animals ingest older plant material. This was evidenced within each grazing period by the increase in the intake of the dead component of vegetation over time, a consequence of the reduced availability of green vegetation within the pasture. The consistent disappearance of approximately 28% of dead forage material by the second day of grazing for all of the grazing periods was unexpected, especially considering the differences in initial biomass and proportion of green biomass at each study period. The increased disappearance of dead forage over time at each study period was consistent and by day 4 and day 5 dead forage accounted for approximately 50% of the diet. The similarities may be a result of the pasture comprising greater than 50% of dead forage at each study period and may be associated with the visual estimation method and possible overestimation of dead forage disappearance. Furthermore, the high levels of dead forage disappearance may be a consequence of the high stocking rate (125 DSE/ ha) and breaking down of the pasture and the animals may have consumed the substantial quantities of dead forage in response to declining pasture biomass. The quantity of dead forage disappearance from day 2 onwards has potential implications in terms of animal performance within a RG system if animals are consuming large amounts of dead material and the quantity of dead material together with the quality warrants further investigation. The proportions of the various plant species consumed by the animals varied for each study period, although the animals consistently consumed the young green vegetation of the available pasture species, similar to that observed by Hodgson (1966) in sheep grazing a set-stocked sward of L. rigidum. The consumption of green vegetative material may be a consequence of the relative proportions of the different plant components and species and their distribution in space (Hodgson 1982) and thus the greater accessibility of the pasture components to the animals. However, the pasture species components selected by the animals were usually higher in quality than the average available green pasture and the deliberate selection of these species by the animals cannot be ignored. The selection of the green component of the major native grasses by the animals was influenced by the DOMD of the major plant species in late summer (February 2010 and 2011) and by the initial green to dead ratio of a plant species in late winter (August - September 2010). Increasing proportions of green herbage of a species was consumed in response to higher DOMD or the initial green to dead ratio of the major species. The results highlight the complex interactions between plants and animals and the need for
further research of this nature at a larger scale, in different seasons and potentially within different (grazing) management systems.

The observed uprooting and removal of small *Austrostipa* spp. plants was consistent for all grazing periods and is presumed to be a result of the sheep dropping or spitting out the plants during grazing. If the uprooting of *Austrostipa* spp. or other species occurred consistently at a larger scale over time it may have the effect of improving the pasture by favouring the growth of the other preferred species. The recorded removal of these plants indicates the effect that grazing animals can have not only on pasture growth and regrowth but also pasture composition.

The technique of direct visual estimation of pasture biomass together with daily grazing rating assessments was very time consuming but allowed the detailed study of the pasture and the species selected by the animals in a relatively simple and non-invasive manner. Further testing and refinement of the methodology at a larger scale is recommended to ascertain whether the observed selection and defoliation of plants by the animals in this study is recorded at a larger scale and in grazing sheep managed within contrasting systems. The repeated defoliation of plants within a paddock by animals managed within a short-duration RG system may be indicative of declining nutrient quality of the diet and the need for a producer to decrease the grazing period of a paddock and/or excessive stocking rates. However, if repeated defoliation of plants occurred within a ‘correctly stocked’ continuously grazed pasture the progressive re-grazing of plants may provide a means of maintaining the quality of the diet by ingesting predominantly green vegetative forage. Furthermore, if animals were to ‘rotate’ their grazing location within the landscape it may be a means of preventing the over-grazing of preferred species (Morris 1969).

### 6.5 Conclusion

The hypothesis that the primary cue of the selection of grazing animals is the green to dead ratio of DM was not substantiated, reflecting the range of values encountered. The green to dead ratio of DM appeared to be the primary cue of selection in August – September, but was not associated with selection in February of 2010 and 2011 when the pasture contained a low proportion of green forage. Animals grazing the pasture in summer similar to the animals in August – September consistently displayed strong selection for the green forage and generally selected the species of highest quality from the pasture; however, the mechanisms and cues underlying selection in late summer are
not clear. The strong selection of green vegetative forage from within a pasture if unmanaged may result in a decline in the species over time and potentially reduce pasture quality. This study highlights the complex interactions that occur between grazing animals and plants that are far from simple. Further testing and refinement of the grazing rating index and pasture assessment methods are recommended and more importantly investigating whether the observed patterns of diet selection are repeated at a larger scale.
Chapter 7. Diet Selection by Ewes Grazing Within Contrasting Grazing Systems and in Different Physiological States

7.1 Introduction

Grazing management systems seek to control the relationship between animals, plants and soil by regulating the number of animals and the duration and location of grazing animals, which affects an animal’s selectivity and distribution within an ecosystem (Beattie 1994). The benefits of a grazing system can be judged in terms of effects on animal production, vegetation or some other parameters including increased SR. As previously outlined (Chapter 4) studies comparing continuous and rotational grazing have demonstrated the complexity of plant-animal interactions (Jensen et al. 1990) with variable results and benefits recorded within different landscapes and pastures and between producers and researchers. For the most part literature has focused on animal production (Morley 1969; Warn et al. 2002; Holst et al. 2006) or pasture quality (Dowling et al. 2006) and few studies to date have investigated the effect of grazing management systems on the quality of the diet selected by animals. Within a RG system the resting of paddocks is designed to allow the regrowth of pasture following grazing and results in animals potentially grazing pastures at different developmental stages and quality than would occur within a CG situation. When animals are moved to new paddocks within a rotation, it is thought the quality of their diet and intake shows a relative increase before subsequently declining in response to a decrease in both available herbage mass and the quality of the remaining herbage (Prache et al. 1998). A reduction in grazing time (and presumably intake) by sheep at the end of a rotation, as observed by Prache et al. (1998), may be due to a reluctance of animals to graze poorer quality forage and forage contaminated by fouling (Demment et al. 1995) and also a response to a decline in biomass (Jamieson and Hodgson 1979). Variations in diet quality associated with grazing systems are not well understood, nor are the impact of diet variations on animal production between CG and RG. It is likely that effects of grazing systems depend upon the manner in which animals are moved around paddocks in relation to seasons and the physiological state of both the animals and the pasture.

The primary objective of this study was to investigate the effects of grazing systems on diet quality, selection and grazing behaviour of ewes managed within differing grazing systems within a native grassland in the Central Tablelands of NSW. The study
involved ewes managed at different SR within contrasting grazing systems at different physiological states (lactating with lambs at foot and when dry and not-pregnant) and the use of intensive pasture monitoring and faecal chemistry analysis. It was hypothesised that the diet quality and selection of CG ewes would be greater than RG ewes.

7.2 Materials and methods

7.2.1 Experiment location and management
The experiment was conducted at the EverGraze Central Tablelands Proof Site over two time periods. The first was when ewes were with lambs and lactating at the end of spring (18th November to 8th December 2010), whilst the second period occurred following weaning when ewes were dry and not pregnant in early autumn (2nd to 22nd March 2011). The experiment involved ewes managed within a CG treatment and a 20-paddock RG treatment. During each study period a single paddock within the 20 paddock RG treatment was monitored and the composition and quality of the diet selected by grazing ewes estimated. The monitored paddock was located within an area identified as a MPZ at the site. Site topography resulted in low, medium and high pasture production zones (Badgery, unpub. data). Simultaneously the composition and quality of the diet selected by ewes managed within the CG system at the site was also monitored.

Refer to Chapter 3, section 3.1 for further information on the experiment location and management including geology, landscape and soil (section 3.1.2), general vegetation (section 3.1.3) and the site management and monitoring (section 3.1.4.2).

7.2.2 Climatic data
Climatic data including temperature, relative humidity, rainfall and wind speed was recorded every 15 min at the site (Figure 7.1). The average daily temperature for the first grazing period in November - December 2010 and the second grazing period in March 2011 was 17°C. The total rainfall for the first and second grazing periods were 20 mm and 34 mm, respectively.
Figure 7.1. Daily rainfall (columns) and average (blue), maximum (green) and minimum (purple) temperatures during the period (January 2010 – August 2011). Lines denote first (18\textsuperscript{th} November – 8\textsuperscript{th} December 2010) and second (2\textsuperscript{nd} – 22\textsuperscript{nd} March 2011) grazing periods.

7.2.3 Animal measurements
The Merino ewes were approximately 5 years of age during the two study periods.

Refer to Chapter 3, section 3.1 for further information on the management of animals at the site (section 3.1.4.2) and during the study period (section 3.2.2).

7.2.4 Stocking rate
Each treatment had different numbers of ewes (and lambs) based upon FOO and this differed throughout the year. Ewe numbers were adjusted after weaning and at scanning (in June) to achieve similar levels of herbage mass in each plot. Stocking rate was also varied by the timing of when lambs were removed from the systems. The removal of lambs was based on the amount of FOO, whether lambs reached a target weight (42 kg) or average growth rate fell below < 100 g/hd/d.

The average (± SE) annual SR for the CG treatment was 6.1 (± 0.53) DSE/ha and for the RG treatment was 7.7 (± 0.40) DSE/ha, although this size difference was not maintained consistently. The SR within each treatment during the two study periods as
well as the grazing intensity and days rest within the RG treatment are presented on a DSE basis in Table 7.1. During the first study period in November - December 2010 when ewes were lactating with lambs at foot and during the second grazing period following weaning when the ewes were dry the animals grazed the monitored paddock within the RG treatment for 1.5 days and 2 days, respectively.

### Table 7.1. Stocking rate (± SE), grazing intensity (during period of grazing during measurements) and rest days prior to grazing for each study period.

<table>
<thead>
<tr>
<th>Lactating ewes with lambs (November - December 2010)</th>
<th>Dry ewes (March 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SR of treatment plot (DSE/ha)</strong></td>
<td><strong>SR of treatment plot (DSE/ha)</strong></td>
</tr>
<tr>
<td>CG 14 ± 1.4</td>
<td>6.1 ± 0.1</td>
</tr>
<tr>
<td>RG 22 ± 0.5</td>
<td>8.6 ± 0.7</td>
</tr>
<tr>
<td><strong>Grazing intensity</strong></td>
<td>-</td>
</tr>
<tr>
<td>CG 35 ± 0.5</td>
<td>49 ± 1.3</td>
</tr>
<tr>
<td>RG 126 ± 1.2</td>
<td>98 ± 1.3</td>
</tr>
<tr>
<td><strong>Grazing days</strong></td>
<td>-</td>
</tr>
<tr>
<td>CG 189 ± 1.2</td>
<td>105 ± 4.1</td>
</tr>
<tr>
<td>RG 37 ± 1.9</td>
<td>-</td>
</tr>
<tr>
<td><strong>Rest days prior to grazing (d)</strong></td>
<td>0</td>
</tr>
<tr>
<td>CG 0</td>
<td>-</td>
</tr>
<tr>
<td>RG 89 ± 1.2</td>
<td>-</td>
</tr>
</tbody>
</table>

* Grazing intensity (or stocking density) = DSE/paddock size (0.175 ha)

During both study periods the duration of each grazing period was limited and utilisation low. In the first instance this was to allow the lactating ewes to meet their high nutrient requirements and during the second period it was to increase the condition of the dry ewes prior to joining, in accordance with the treatment design.

#### 7.2.5 Live weight and body condition score

Ewe live weight data were adjusted to account for monthly wool growth effects (described in section 7.2.6). Average lamb weight and BCS were calculated from the first weighing post-partum (September 2010) to weaning (mid - December 2010).

#### 7.2.6 Fleece weight and wool growth

The fleece weight of each ewe was recorded at shearing (May 2011). Average monthly wool growth was calculated and used to adjust the average live weight of the ewes over time to eliminate wool growth effects from the live weight data.

#### 7.2.7 Faecal collection and analysis

Three fresh (composite) faecal samples were collected from pasture at the same time each day from each treatment (0900 h from the RG treatment and 1000 h from the CG treatment). Each composite sample comprised five faecal samples (aiming to represent five sheep). Samples were collected from both treatments for the duration of the grazing of the RG paddock and four subsequent days after the completion of grazing to account
for the rate of passage of digesta. Faecal collection methods and analysis are described in Chapter 3, sections 3.2.2.1 and 3.5.2.

7.2.8 GPS tracking and grazing behaviour
During each replicate study eight GPS collars (Blue Telemetry Ltd, Scotland) were deployed and fitted to four randomly selected ewes grazing within each treatment replicate for the duration of each (replicate) study. Refer to Chapter 3, section 3.4 for a description of the relevant methods.

Technical problems were anticipated and it was recognised that data from all eight collar deployments for each of the three replicates (24 in total) for each study period would not be available due to vagaries in signal transmissions in the hilly country at the site. From the first (lactating ewes with lambs) and second (dry non-pregnant ewes) studies data from 14 and 15 collars were available for analysis, respectively. The behavioural activity of each animal was determined as either active (grazing, graze walking, walking with head down) or inactive (standing with head up, lying or sitting with head up, walking with head up) as described by Umstätter et al. (2008). The proportion of time the animals were active and inactive was compared between the CG and RG systems.

7.2.8.1 Observation of animal location
The location and activity of the animals within each grazing treatment was recorded every 20 min by the same observer for the duration of the first day (0600 h to 1800 h). Observation data was used to verify recorded GPS locations, animal activity and identify areas of high- and low-utilisation by the animals within the CG paddocks.

7.2.9 Plant study
7.2.9.1 Pasture biomass and phenology
The pasture biomass and composition of a monitored paddocks within the RG treatment was assessed prior to and following grazing at 60 permanent points in a regular grid across each paddock. Within the CG treatment pasture biomass and composition was assessed within two areas identified as HU, where animals spent the highest proportion of their time grazing and LU, where animals spent the least amount of time grazing during the initial day of monitoring. Within each area the pasture was assessed at 20
locations (10 m intervals) along two 90 m transects. For both treatments the pasture biomass and composition was assessed using a 0.25 m\(^2\) (0.5 m x 0.5 m) quadrat.

Refer to Chapter 3, section 3.3.2 for further information on the methods of pasture study including determining pasture biomass, phenology and species selection (section 3.3.1.1).

**7.2.9.2 Plant species selection**

The total, green, dead and litter biomass (kg DM/ha) and ground cover (%) were estimated by direct visual assessment (Campbell and Arnold 1973). The botanical composition of each quadrat was estimated by direct visual assessment of the green and dead biomass (kg DM/ha) of all species present. The estimated values were corrected using the estimated and actual values from calibration quadrats that were sorted into dead and green components. The developmental stage of each species was recorded at the initial pasture assessment (prior to grazing) as either; vegetative (V), reproductive (R) and senescent (Sc). Vegetative referred to green, actively growing plants prior to flowering, with minimal stem development. Reproductive included plants in flowering and fruit development stage, with more stem growth. Senescent referred to plants with dry stems, leaves, seeds and seed pods.

Refer to Chapter 3 for the details of plant species selection of ewes grazing within the RG treatment (section 3.1.1) and the CG treatment (section 3.3.2.2).

**7.2.9.3 Estimated diet composition**

The average daily diet composition of the animals managed within the RG treatment was estimated using the same technique outlined in section 3.3.1.2. The plant species selected by the animals managed within the CG treatment was identified by the grazing rating index. As it was not possible to estimate the animal’s intake the data may be less precise.

**7.2.9.4 Evaluation of the nutritive value of plant species components**

Plant material of the major pasture species and of the species identified as being consumed by the animals, was hand-plucked from the RG paddock prior to grazing. Additional samples were collected following daily identification of the pasture species consumed by the animals. Samples were collected from the CG treatment at the same time as the pasture biomass and composition was assessed within the area of HU. Refer
to Chapter 3 for details of methods of sample collection and preparation of the major pasture species (section 3.3.1.4) and the analytical procedures (section 3.5.2).

7.2.10 Estimation of daily nutrient intake
Individual ewe intake and maintenance requirements were predicted using the decision support tool GrazFeed® (Freer et al. 2010) that incorporated the pasture, weather conditions for the two study periods as well as ewe and lamb condition.

The daily DM intake, digestibility, CP, ME intake and live weight gain of the animals was provided and used to assess the accuracy of the faecal predictive equations.

7.2.11 Estimation of diet quality from faecal predictive equations
The animal’s dietary OMD was estimated (OMD<sub>W</sub>) using a predictive model developed by Wang et al. (2009) and the animal’s dietary ME was estimated (ME<sub>M</sub>) using an equation derived by Mahipala et al. (2009). The details of the equations are outlined in Chapter 3, section 3.6.2.

7.2.12 Investigation of intake regulation
Data from both treatments and sampling periods was analysed to determine any relationships between the proportion of green forage consumed and the plant species, quantity and quality as well as the proportion of time the animals spent active. The quantity of green and dead DM within the pasture was included in the model, however, the quality of dead DM at the time was not analysed and as a consequence a value for dead DMD within GrazFeed® of 40% was applied based upon previous analysis of pasture samples harvested at the site (Badgery unpub. data). The proportion of green DM consumed relative to the initial green to dead ratio and the DOMD of a species were estimated for the RG treatment using the pre- and post-grazing biomass.

7.2.13 Statistical analyses
Individual animal data was analysed to determine any effects of between replicates. A ewe’s pregnancy status (twins or single) was included in the analysis of ewe live weight and birth type (twin or single) was included in the analysis of lamb birth and live weight. The average pasture biomass pre- and post-grazing as well as animal live weight, BCS and animal activity (active versus inactive) were analysed using ANOVA (Genstat® 13<sup>th</sup> edn, Hemel Hempstead United Kingdom) and differences were significant when p < 0.05.
Relationships between the proportion of green forage consumed and the plant species, quantity and quality as well as the proportion of time the animals spent active were analysed using regression analysis in Genstat. To examine the influence of green to dead ratio of DM and plant species quality on the percentage of green forage consumed the variables were log-transformed.

7.3 Results
For clarity of presentation the results of each study period; ewes with lambs (November - December 2010) and dry ewes (March 2011) are presented separately. Ewe and lamb live weight and BCS over time are presented following the data relating to the two study periods.

7.3.1 Ewes with lambs

7.3.1.1 Pasture composition and plant species selection
The pre- and post-grazing total and green herbage mass of each species as well as litter and ground cover (%) for the RG treatment are presented in Table 7.2. The pasture within the RG treatment was dominated by the grasses *Microlaena stipoides* (42.8%), *Austrodanthonia* spp. (18.6%), *Lolium rigidum* (13.8%), *Elymus scaber* (6.4%) and the forb *Hypochaeris radicata* (3.7%). Following grazing the total and green herbage mass as well as litter biomass declined (p < 0.001). The biomass of green *M. stipoides* (p < 0.001), *Austrodanthonia* spp. (p < 0.05) and *H. radicata* (p < 0.001) was reduced as a consequence of the animals selecting these pasture components that represented 18.9%, 6.7% and 3.3% of the initial available pasture, respectively. The green biomass of *L. rigidum* was also substantially reduced (p > 0.05) and the animals noticeably selected *Trifolium subterraneum* that accounted for 1.8% of the available pasture. The selected species were in a vegetative, late vegetative and early reproductive stage of development.

The pasture compositions of the areas of HU and LU within the CG treatment are presented in Table 7.3. The pasture within the HU area was located in a HPZ of the paddock and comprised *M. stipoides* (53.9%), *L. rigidum* (16.3%), *T. subterraneum* (14.2%), *Holcus lanatus* (4.7%), *Austrodanthonia* spp. (3.2%) and *H. radicata* (1.3%). From the grazing rating it was identified that the animals had grazed green *M. stipoides*, *H. radicata*, *L. rigidum*, *H. lanatus* and *T. subterraneum* to an average (± SE) grazing rating value of: 1.7 (± 0.21), 3.0 (± 0.28), 1.8 (± 0.22), 2.0 (± 0.32) and 2.3 (± 0.20),
respectively. All of the species identified as being grazed by the animals were in a vegetative state of development. Within the area of LU that was located within a LPZ of the paddock the pasture consisted of *Austrodanthonia* spp. (61%), *Austrostipa* spp. (14%), *L. rigidum* (10%), *H. radicata* (4%), *Acetosella vulgaris* (2%) and *M. stipoides* (2%). Minimal grazing was evident within the area, and a grazing rating > 0 was not given, but where grazing was observed the animals had grazed green *Austrodanthonia* spp., *L. rigidum* and *H. radicata*.

The predicted DM intake of an individual ewe (and lamb) grazing within the CG and RG systems from GrazFeed® was 1.4 (1.0) and 1.3 (0.9) kg/d, respectively.

### 7.3.1.2 Pasture quality

The nutritive value of the green component of the pasture species and the available average green pasture for the RG and CG treatments are shown in Tables 7.4 and 7.5, respectively.

Within the RG treatment the animals selected green *M. stipoides*, *Austrodanthonia* spp., *H. radicata*, *L. rigidum* and *T. subterraneum*. Green *M. stipoides*, *H. radicata*, and *T. subterraneum* were higher in N than the average green pasture (p < 0.001). *Trifolium subterraneum* was higher in DOMD and ME than the average green pasture (p < 0.05).

The animals grazing within the HU area of the CG treatment selected green *M. stipoides*, *H. radicata*, *L. rigidum*, *H. lanatus* and *T. subterraneum*. *Holcus lanatus* and *T. subterraneum* were of higher quality than the average green pasture within the area in terms of DOMD (p < 0.05) and ME (p < 0.05). The N content of *T. subterraneum* was higher (p < 0.05) than all pasture species components sampled in the HU area. *Lolium rigidum* was the pasture species with less than the average nutritive values for available green pasture in late spring.

The qualities of the pasture samples harvested from the HU area of the CG treatment were greater (p > 0.05) than the corresponding samples from the RG treatment (with the exception of *L. rigidum* that recorded the same quality).
Table 7.2. Average (± SE) pre- and post-grazing biomass, proportion of species in the pasture and the physiological developmental stage of each species for the RG treatment.

<table>
<thead>
<tr>
<th>Species</th>
<th>Pre-grazing (kg DM/ha)</th>
<th>Post-grazing (kg DM/ha)</th>
<th>Developmental stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Herbage mass (Proportion of pasture %)</td>
<td>Herbage mass (Proportion of pasture %)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3832 ± 136.0</td>
<td>3106 ± 119.4**</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>1674 ± 80.8</td>
<td>1139 ± 60.4**</td>
<td></td>
</tr>
<tr>
<td>Litter</td>
<td>111 ± 3.9</td>
<td>149 ± 6.2**</td>
<td></td>
</tr>
<tr>
<td>**Cover (%)</td>
<td>97 ± 0.5</td>
<td>97 ± 0.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Pre-grazing (kg DM/ha)</th>
<th>Post-grazing (kg DM/ha)</th>
<th>Developmental stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Herbage mass (Proportion of pasture %)</td>
<td>Herbage mass (Proportion of pasture %)</td>
<td></td>
</tr>
<tr>
<td>Native grasses (C3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Microlaena stipoides</em></td>
<td>726 ± 43.3 (18.9)</td>
<td>463 ± 30.4** (14.9)</td>
<td>R</td>
</tr>
<tr>
<td>Dead</td>
<td>915 ± 51.1 (23.9)</td>
<td>826 ± 46.6 (26.6)</td>
<td></td>
</tr>
<tr>
<td><strong>Austrodanthonia spp.</strong></td>
<td>257 ± 23.2 (6.7)</td>
<td>185 ± 18.3* (5.9)</td>
<td>R</td>
</tr>
<tr>
<td>Dead</td>
<td>455 ± 42.8 (11.9)</td>
<td>385 ± 35.1 (12.4)</td>
<td></td>
</tr>
<tr>
<td><strong>Austrostipa spp.</strong></td>
<td>3 ± 1.4 (0.1)</td>
<td>3 ± 1.1 (0.1)</td>
<td>Sc</td>
</tr>
<tr>
<td>Dead</td>
<td>28 ± 7.6 (0.7)</td>
<td>26 ± 7.2 (0.8)</td>
<td></td>
</tr>
<tr>
<td><strong>Elymus scaber</strong></td>
<td>75 ± 10.3 (2.0)</td>
<td>59 ± 8.4 (1.9)</td>
<td>R</td>
</tr>
<tr>
<td>Dead</td>
<td>169 ± 21.5 (4.4)</td>
<td>149 ± 18.9 (4.8)</td>
<td></td>
</tr>
<tr>
<td>Native grasses (C4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Bothriochloa macra</em></td>
<td>0 ± 0.4 (0.0)</td>
<td>0 ± 0.1 (0.0)</td>
<td>V</td>
</tr>
<tr>
<td>Dead</td>
<td>1 ± 1.2 (0.0)</td>
<td>1 ± 1.0 (0.0)</td>
<td></td>
</tr>
<tr>
<td>Introduced grasses (C3)</td>
<td></td>
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<tr>
<td><em>Lolium rigidum</em></td>
<td>291 ± 33.9 (7.6)</td>
<td>215 ± 25.8 (6.9)</td>
<td>R</td>
</tr>
<tr>
<td>Dead</td>
<td>240 ± 30.0 (6.3)</td>
<td>212 ± 27.8 (6.8)</td>
<td></td>
</tr>
<tr>
<td><em>Poa bulbosa</em></td>
<td>0 ± 0.0 (0.0)</td>
<td>0 ± 0.0 (0.0)</td>
<td>Sc</td>
</tr>
<tr>
<td>Dead</td>
<td>2 ± 2.3 (0.1)</td>
<td>2 ± 2.2 (0.1)</td>
<td></td>
</tr>
<tr>
<td><strong>Holcus lanatus</strong></td>
<td>36 ± 22.2 (0.9)</td>
<td>24 ± 16.2 (0.8)</td>
<td>R</td>
</tr>
<tr>
<td>Dead</td>
<td>17 ± 11.3 (0.4)</td>
<td>12 ± 7.8 (0.4)</td>
<td></td>
</tr>
<tr>
<td><em>Vulpia spp.</em></td>
<td>14 ± 4.6 (0.4)</td>
<td>13 ± 4.2 (0.4)</td>
<td>R</td>
</tr>
<tr>
<td>Dead</td>
<td>20 ± 6.8 (0.5)</td>
<td>20 ± 6.7 (0.6)</td>
<td></td>
</tr>
<tr>
<td><em>Bromus hordeaceus</em></td>
<td>13 ± 3.3 (0.3)</td>
<td>12 ± 3.0 (0.4)</td>
<td>R</td>
</tr>
<tr>
<td>Dead</td>
<td>12 ± 3.9 (0.3)</td>
<td>12 ± 3.9 (0.4)</td>
<td></td>
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<tr>
<td>Other monocotyledons (introduced)</td>
<td></td>
<td></td>
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<tr>
<td><em>Juncus spp.</em></td>
<td>41 ± 22.0 (1.1)</td>
<td>35 ± 19.1 (1.1)</td>
<td>Sc</td>
</tr>
<tr>
<td>Dead</td>
<td>50 ± 25.2 (1.3)</td>
<td>47 ± 23.2 (1.5)</td>
<td></td>
</tr>
<tr>
<td><em>Asphodelus fistulosus</em></td>
<td>0 ± 0.2 (0.0)</td>
<td>0 ± 0.2 (0.0)</td>
<td>Sc</td>
</tr>
<tr>
<td>Dead</td>
<td>44 ± 7.5 (1.2)</td>
<td>41 ± 7.1 (1.3)</td>
<td></td>
</tr>
<tr>
<td>Legume (introduced)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Trifolium subterraneum</em></td>
<td>44 ± 9.7 (1.1)</td>
<td>29 ± 7.0 (0.9)</td>
<td>R</td>
</tr>
<tr>
<td>Dead</td>
<td>26 ± 8.6 (0.7)</td>
<td>25 ± 8.4 (0.8)</td>
<td></td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Carthamus lanatus</em></td>
<td>27 ± 7.2 (0.7)</td>
<td>24 ± 6.4 (0.8)</td>
<td>R</td>
</tr>
<tr>
<td>Dead</td>
<td>22 ± 6.7 (0.6)</td>
<td>23 ± 6.8 (0.7)</td>
<td></td>
</tr>
<tr>
<td><em>Hypochaeris radicata</em></td>
<td>125 ± 11.3 (3.3)</td>
<td>60 ± 5.5** (1.9)</td>
<td>V</td>
</tr>
<tr>
<td>Dead</td>
<td>17 ± 2.6 (0.4)</td>
<td>12 ± 1.9 (0.4)</td>
<td></td>
</tr>
<tr>
<td><em>Acetosella vulgaris</em></td>
<td>22 ± 5.7 (0.6)</td>
<td>17 ± 4.3 (0.5)</td>
<td>R</td>
</tr>
<tr>
<td>Dead</td>
<td>29 ± 7.8 (0.8)</td>
<td>27 ± 7.1 (0.9)</td>
<td></td>
</tr>
</tbody>
</table>

A superscript in the post-grazing column indicates a significant difference over time * (p <0.05); ** (p < 0.001)
Table 7.3. Average (± SE) biomass, the proportion of each species in the pasture and
the physiological developmental stage of each plant species of areas of high- and low-
utilisation within the CG treatment.

<table>
<thead>
<tr>
<th></th>
<th>High utilisation (kg DM/ha)</th>
<th>Low utilisation (kg DM/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1829 ± 146.9</td>
<td>1041 ± 112.6</td>
</tr>
<tr>
<td>Green</td>
<td>972 ± 87.6</td>
<td>342 ± 45.2</td>
</tr>
<tr>
<td>Litter</td>
<td>57 ± 5.7</td>
<td>69 ± 7.1</td>
</tr>
<tr>
<td>Cover (%)</td>
<td>99 ± 0.3</td>
<td>62 ± 4.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Native grasses (C3)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>Developmental stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>Developmental stage</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Microlaena stipoides</em></td>
<td>Green: 501 ± 56.4, Dead: 485 ± 58.1</td>
<td>late V</td>
<td>9 ± 4.9, Dead: 9 ± 8.0</td>
<td></td>
</tr>
<tr>
<td><em>Austrodanthonia spp.</em></td>
<td>Green: 46 ± 23.8, Dead: 14 ± 6.4</td>
<td>R</td>
<td>224 ± 43.0, Dead: 415 ± 70.2</td>
<td></td>
</tr>
<tr>
<td><em>Austrostipa spp.</em></td>
<td>Green: 0 ± 0.2, Dead: 0 ± 0.0</td>
<td>R</td>
<td>29 ± 6.5, Dead: 114 ± 22.8</td>
<td></td>
</tr>
<tr>
<td><em>Elymus scaber</em></td>
<td>Green: 0 ± 0.2, Dead: 0 ± 0.0</td>
<td>R</td>
<td>0 ± 0.2, Dead: 0 ± 0.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Introduced grasses (C3)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>Developmental stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>Developmental stage</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Lolium rigidum</em></td>
<td>Green: 178 ± 29.6, Dead: 120 ± 21.5</td>
<td>R</td>
<td>40 ± 15.8, Dead: 64 ± 24.1</td>
<td></td>
</tr>
<tr>
<td><em>Poa bulbosa</em></td>
<td>Green: 0 ± 0.2, Dead: 0 ± 0.0</td>
<td>V</td>
<td>0 ± 0.0, Dead: 0 ± 0.0</td>
<td></td>
</tr>
<tr>
<td><em>Holcus lanatus</em></td>
<td>Green: 52 ± 14.7, Dead: 34 ± 15.9</td>
<td>V</td>
<td>0 ± 0.0, Dead: 0 ± 0.0</td>
<td></td>
</tr>
<tr>
<td><em>Vulpia spp.</em></td>
<td>Green: 1 ± 0.7, Dead: 0 ± 0.2</td>
<td>R</td>
<td>0 ± 0.0, Dead: 0 ± 0.0</td>
<td></td>
</tr>
<tr>
<td><em>Bromus hordeaceus</em></td>
<td>Green: 4 ± 2.5, Dead: 1 ± 0.9</td>
<td>R</td>
<td>0 ± 0.0, Dead: 0 ± 0.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other monocotyledons (introduced)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>Developmental stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>Developmental stage</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Juncus spp.</em></td>
<td>Green: 33 ± 32.4, Dead: 9 ± 8.6</td>
<td>Sc</td>
<td>0 ± 0.0, Dead: 0 ± 0.0</td>
<td></td>
</tr>
<tr>
<td><em>Asphodelus fistulosus</em></td>
<td>Green: 1 ± 0.4, Dead: 0 ± 0.1</td>
<td>R</td>
<td>0 ± 0.0, Dead: 2 ± 0.9</td>
<td></td>
</tr>
<tr>
<td><em>Trifolium subterraneum</em></td>
<td>Green: 131 ± 16.5, Dead: 130 ± 10.5</td>
<td>R</td>
<td>0 ± 0.5, Dead: 1 ± 0.8</td>
<td></td>
</tr>
<tr>
<td><em>Hypochaeris radicata</em></td>
<td>Green: 22 ± 5.9, Dead: 1 ± 0.7</td>
<td>V</td>
<td>30 ± 16.6, Dead: 11 ± 11.0</td>
<td></td>
</tr>
<tr>
<td><em>Acetosella vulgaris</em></td>
<td>Green: 3 ± 1.8, Dead: 5 ± 4.3</td>
<td>R</td>
<td>10 ± 10.3, Dead: 15 ± 14.5</td>
<td></td>
</tr>
</tbody>
</table>
Table 7.4. Average (± SE) N content, DOMD and ME of green pasture species components and average green pasture for RG treatment in late spring.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Plant species</th>
<th>N (%)</th>
<th>DOMD (%)</th>
<th>ME (MJ/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native grasses (C3)</td>
<td><em>Microlaena stipoides</em></td>
<td>2.6 ± 0.14(^a)</td>
<td>57 ± 1.7(^{bc})</td>
<td>8.6 ± 0.35(^{bc})</td>
</tr>
<tr>
<td></td>
<td><em>Austrodanthonia spp.</em></td>
<td>1.6 ± 0.22(^b)</td>
<td>51 ± 0.9(^a)</td>
<td>7.2 ± 0.15(^{ab})</td>
</tr>
<tr>
<td></td>
<td><em>Elymus scaber</em></td>
<td>1.3 ± 0.08(^a)</td>
<td>47 ± 2.0(^{a})</td>
<td>6.6 ± 0.40(^{\text{---}})</td>
</tr>
<tr>
<td>Introduced grasses (C3)</td>
<td><em>Lolium rigidum</em></td>
<td>1.4 ± 0.05(^{ab})</td>
<td>60 ± 2.5(^{ab})</td>
<td>9.1 ± 0.50(^c)</td>
</tr>
<tr>
<td></td>
<td><em>Holcus lanatus</em></td>
<td>1.6 ± 0.00(^{bc})</td>
<td>52 ± 0.0(^{a})</td>
<td>7.5 ± 0.00(^{bc})</td>
</tr>
<tr>
<td>Legume (introduced)</td>
<td><em>Trifolium subterraneum</em></td>
<td>3.0 ± 0.20(^{bc})</td>
<td>62 ± 1.0(^{a})</td>
<td>9.5 ± 0.20(^c)</td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td><em>Hypochaeris radicata</em></td>
<td>2.6 ± 0.16(^{bc})</td>
<td>60 ± 1.5(^{ab})</td>
<td>9.2 ± 0.26(^c)</td>
</tr>
<tr>
<td>Average green pasture</td>
<td></td>
<td>1.9 ± 0.17(^{bc})</td>
<td>54 ± 4.0(^{a})</td>
<td>8.0 ± 0.80(^{bc})</td>
</tr>
</tbody>
</table>

\(^{abc}\) values with a different superscript in the same column are significantly different (p < 0.05)

Table 7.5. Average (± SE) N content, DOMD and ME of green pasture species components and average green pasture for CG treatment in late spring. All species were harvested from the HU areas.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Plant species</th>
<th>N (%)</th>
<th>DOMD (%)</th>
<th>ME (MJ/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native grasses (C3)</td>
<td><em>Microlaena stipoides</em></td>
<td>2.7 ± 0.12(^a)</td>
<td>59 ± 2.3(^{bc})</td>
<td>8.9 ± 0.46(^{a})</td>
</tr>
<tr>
<td>Introduced grasses (C3)</td>
<td><em>Lolium rigidum</em></td>
<td>1.9 ± 0.26(^{bc})</td>
<td>60 ± 2.5(^{bc})</td>
<td>9.0 ± 0.10(^{ab})</td>
</tr>
<tr>
<td></td>
<td><em>Holcus lanatus</em></td>
<td>3.0 ± 0.00(^{bc})</td>
<td>63 ± 0.9(^{bc})</td>
<td>9.8 ± 0.15(^{bc})</td>
</tr>
<tr>
<td>Dicotyledons (introduced)</td>
<td><em>Trifolium subterraneum</em></td>
<td>3.9 ± 0.35(^{bc})</td>
<td>64 ± 1.5(^{c})</td>
<td>10.0 ± 0.30(^{bc})</td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td><em>Hypochaeris radicata</em></td>
<td>3.0 ± 0.25(^{bc})</td>
<td>62 ± 0.9(^{bc})</td>
<td>9.5 ± 0.15(^{bc})</td>
</tr>
<tr>
<td>HU Average green pasture</td>
<td></td>
<td>2.4 ± 0.27(^{a})</td>
<td>57 ± 0.7(^{a})</td>
<td>8.7 ± 0.19(^{a})</td>
</tr>
<tr>
<td>LU- Average green pasture</td>
<td></td>
<td>1.6 ± 0.09(^{a})</td>
<td>48 ± 1.2(^{a})</td>
<td>6.7 ± 0.20(^{a})</td>
</tr>
</tbody>
</table>

\(^{abc}\) values with a different superscript in the same column are significantly different (p < 0.05)

7.3.1.3 Predicted diet quality of ewes

The predicted DM intake of an individual ewe and lamb grazing within the CG and RG systems from GrazFeed® are shown in Table 7.6. The predicted CP and ME intakes and daily live weight loss for CG ewes were greater (p < 0.05) than RG ewes. Similarly, the predicted CP and ME intakes and daily live weight gain for CG lambs were greater (p < 0.05) than RG lambs.
Table 7.6. Predicted dietary intake and quality of lactating ewes and lambs in late spring (GrazFeed®)

<table>
<thead>
<tr>
<th>Diet parameters</th>
<th>Lactating ewes</th>
<th>Lambs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CG</td>
<td>RG</td>
</tr>
<tr>
<td>DM intake (kg/hd/d)</td>
<td>1.39</td>
<td>1.30</td>
</tr>
<tr>
<td>DM digestibility (%)</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Crude protein (g/d)</td>
<td>195</td>
<td>169</td>
</tr>
<tr>
<td>ME intake (MJ/d)</td>
<td>11.9</td>
<td>11</td>
</tr>
<tr>
<td>Weight gain (g/d)</td>
<td>-37</td>
<td>-30</td>
</tr>
</tbody>
</table>

7.3.1.4 Estimated diet quality of ewes

The estimated OMDₜ of the diet of the CG ewes was higher (p < 0.001) for the first three days of faecal sampling and day 6 but similar (p > 0.05) to the RG ewes on days 4 and 5 (Figure 7.2). The CG ewes consumed an average diet of higher OMD (p < 0.001) than RG ewes (61% vs. 59%). The OMDₜ of the diet of both treatments varied over time and was of a similar value to the DMD (62%) of the diet of both treatments predicted by GrazFeed®.

The estimated MEM of the diet of RG ewes was higher (p < 0.001) for the first three days of faecal sampling and similar (p > 0.05) to the CG ewes on days 4 - 6 (Figure 7.3). The CG ewes consumed an average diet that was of lower MEM value (p < 0.001) than RG ewes (5.4 vs. 6.1). The observed trend of the diet of RG animals in which MEM increased from day 1 to day 2 before declining on day 3 and increasing slightly on day 6 reflected the movement of the animals within the system. The predicted MEM intake of CG and RG animals, based upon the GrazFeed® predicted DM intake, was 7.6 and 7.9 MJ/d, respectively. These values were substantially lower than the GrazFeed® predicted ME intakes of 11.9 MJ/d for the CG animals and 11 MJ/d for the RG ewes.

The ME value of the diets of RG and CG ewes followed a similar trend over time.
Figure 7.2. Average (± SE) OMD\textsubscript{W} of the diet consumed by lactating ewes (with lambs at foot) grazing within differing grazing systems over six days in late spring. CG (green); RG (blue)

Figure 7.3. Average (± SE) ME\textsubscript{M} of the diet consumed by lactating ewes (with lambs at foot) grazing within differing grazing systems over six days in late spring. CG (green); RG (blue)
7.3.1.5 Animal activity
The proportion of times ewes managed within the RG and CG treatments were engaged in either active or inactive behaviour is shown in Table 7.7. The animals spent approximately half of their time in an active state and there was no difference in the proportion of time the animals spent in an active or inactive state between grazing systems.

Table 7.7. Proportion of time (± SE) lactating ewes (with lambs) managed within differing grazing systems spent in an active or inactive state.

<table>
<thead>
<tr>
<th></th>
<th>Active</th>
<th>Inactive</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG</td>
<td>0.52 ± 0.04</td>
<td>0.48 ± 0.04</td>
</tr>
<tr>
<td>RG</td>
<td>0.47 ± 0.03</td>
<td>0.53 ± 0.03</td>
</tr>
</tbody>
</table>

7.3.1.6 Animal live weight and BCS
The average live weight, BCS and change in weight over time of the ewes and lambs prior to and following the study period are presented in Table 7.8 and Table 7.9, respectively.

The average number of lambs per ewe was similar (p > 0.05) between the grazing systems (CG = 1.5 (± 0.08); RG = 1.5 (± 0.11)). Ewes managed within the CG system were initially heavier (p < 0.05) with a higher BCS (p < 0.05) than ewes grazing within the RG system, reflecting prior grazing history. Similarly, the live weight (p < 0.05) and BCS (p < 0.05) of the CG ewes was greater than ewes managed within the RG system at the end of the study period. However, there was no difference (p > 0.05) in the change of live weight over the study period between the systems, with the live weight of all ewes declining over time. The live weight and BCS of lambs was comparable to the ewes within each grazing system; lambs within the CG system were of a greater (p < 0.001) live weight pre and post the study period than lambs within the RG system. Over the study period the CG lambs had greater (p < 0.05) gain in live weight than the RG lambs. The BCS of CG and RG lambs prior to the study was similar (p < 0.05) but by the end of the study period the CG lambs had a higher (p < 0.05) BCS than lambs grazing within the RG system. Similar to the higher SR of the RG, the number of lambs/ha within the RG system was greater (p < 0.05) than the CG system (5.5 vs. 3.9 lambs/ha).
Table 7.8. Average (± SE) ewe live weight, BCS and live weight change over the first study period (November – December 2010)

<table>
<thead>
<tr>
<th></th>
<th>Pre- study period</th>
<th>Post- study period</th>
<th>Live weight change (g/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Live weight (kg)</td>
<td>BCS</td>
<td>Live weight (kg)</td>
</tr>
<tr>
<td>CG</td>
<td>70 ± 1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.4 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>66 ± 1.2&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>RG</td>
<td>64 ± 1.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.2 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>61 ± 1.4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Values in the same column with a different superscript are significantly different (p < 0.05)

Table 7.9. Average (± SE) lamb live weight, BCS and live weight change over the first study period (November – December 2010)

<table>
<thead>
<tr>
<th></th>
<th>Pre- study period</th>
<th>Post- study period</th>
<th>Live weight change (g/d)</th>
<th>Lambs/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Live weight (kg)</td>
<td>BCS</td>
<td>Live weight (kg)</td>
<td>BCS</td>
</tr>
<tr>
<td>CG</td>
<td>30 ± 0.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.1 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36 ± 0.8&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.4 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>RG</td>
<td>26 ± 0.6&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.1 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30 ± 0.7&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.0 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Values in the same column with a different superscript are significantly different <sup>ab</sup>(p < 0.05); <sup>cd</sup>(p < 0.001)

7.3.2 Dry ewes

7.3.2.1 Pasture composition and plant species selection

The pre- and post-grazing total and green herbage mass of each species as well as litter and ground cover (%) for the RG treatment are presented in Table 7.10. The pasture within the RG treatment was dominated by *M. stipoides* (46.2%), *Austrodanthonia* spp. (23.3%), *Bothriochloa macra* (12.9%), *E. scaber* (3.8%), *H. radicata* (2.9%) and *Juncus* spp. (1.6%). Following grazing the total herbage mass (p < 0.05) and green herbage mass (p < 0.001) were significantly reduced and litter biomass was significantly increased (p < 0.001). The biomass of green *M. stipoides* (p < 0.05) and *H. radicata* (p < 0.001) was reduced as a consequence of the animals selecting these pasture components that represented 20.6% and 0.9% of the total pasture, respectively. The species selected by the animals were in a vegetative and early reproductive stage of development.

The pasture compositions of the areas of HU and LU within the CG treatment are presented in Table 7.11. The pasture within the HU area comprised *M. stipoides* (56.5%), *H. lanatus* (32.8%), *Austrodanthonia* spp. (2.3%), *E. scaber* (0.8%), *Paspalum dilatatum* (1.4%), *H. radicata* (0.1%), *L. rigidum* (0.1%) and *T. subterraneum* (0.1%).

From the grazing rating it was identified the animals had grazed green *M. stipoides*, *H. lanatus*, *H. radicata*, and *P. dilatatum* to an average (± SE) grazing rating value of: 2.3
(± 0.25), 2.6 (± 0.24), 3.1 (± 0.14) and 3.5 (± 0.22), respectively. The species identified as consumed by the animals were in a vegetative to reproductive state of development. Within the area of LU the pasture consisted of *Austrodanthonia* spp. (42.9%), *B. macra* (16.1%), *M. stipoides* (9.4%), *Austrostipa* spp. (4.6%), *E. scaber* (1.1%) and *H. radicata* (1.0%). Very little grazing was evident within the area but where grazing was observed the animals had grazed green *M. stipoides*, *H. radicata* and *B. macra*. The predicted (GrazFeed®) DM intakes for an individual ewe grazing within the CG and RG systems were 1.05 and 1.04 kg/d, respectively.
Table 7.10. Average (± SE) pre- and post-grazing biomass and the proportion the species contributed to the pasture of RG treatment and the physiological developmental stage of each species.

<table>
<thead>
<tr>
<th></th>
<th>Pre-grazing (kg DM/ha)</th>
<th>Post-grazing (kg DM/ha)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Developmental stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>3895 ± 99.1</td>
<td>3518 ± 103.7*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>1272 ± 44.4</td>
<td>997 ± 39.8**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Litter</td>
<td>163 ± 3.6</td>
<td>206 ± 5.7**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover (%)</td>
<td>98 ± 0.4</td>
<td>98 ± 0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Native grasses (C3)

**Microlaena stipoides**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>802 ± 51.2</td>
<td>(20.6)</td>
<td>617 ± 43.2*</td>
<td>(17.5)</td>
</tr>
<tr>
<td>Dead</td>
<td>995 ± 68.9</td>
<td>(25.6)</td>
<td>945 ± 66.5</td>
<td>(26.9)</td>
</tr>
</tbody>
</table>

**Austrodanthonia spp.**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>164 ± 19.0</td>
<td>(4.2)</td>
<td>150 ± 18.0</td>
<td>(4.3)</td>
</tr>
<tr>
<td>Dead</td>
<td>742 ± 75.0</td>
<td>(19.1)</td>
<td>720 ± 72.8</td>
<td>(20.5)</td>
</tr>
</tbody>
</table>

**Austrostipa spp.**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>1 ± 0.3</td>
<td>(0.0)</td>
<td>1 ± 0.3</td>
<td>(0.0)</td>
</tr>
<tr>
<td>Dead</td>
<td>4 ± 1.7</td>
<td>(0.1)</td>
<td>4 ± 1.7</td>
<td>(0.1)</td>
</tr>
</tbody>
</table>

**Elymus scaber**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>0 ± 0.0</td>
<td>(0.0)</td>
<td>0 ± 0.0</td>
<td>(0.0)</td>
</tr>
<tr>
<td>Dead</td>
<td>148 ± 19.3</td>
<td>(3.8)</td>
<td>134 ± 17.5</td>
<td>(3.8)</td>
</tr>
</tbody>
</table>

Native grasses (C4)

**Bothriochloa macra**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>210 ± 27.4</td>
<td>(5.4)</td>
<td>166 ± 22.9</td>
<td>(4.7)</td>
</tr>
<tr>
<td>Dead</td>
<td>294 ± 42.2</td>
<td>(7.5)</td>
<td>281 ± 40.7</td>
<td>(8.0)</td>
</tr>
</tbody>
</table>

Introduced grasses (C3)

**Lolium rigidum**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>0 ± 0.0</td>
<td>(0.0)</td>
<td>0 ± 0.0</td>
<td>(0.0)</td>
</tr>
<tr>
<td>Dead</td>
<td>10 ± 4.1</td>
<td>(0.2)</td>
<td>7 ± 3.1</td>
<td>(0.2)</td>
</tr>
</tbody>
</table>

**Poa bulbosa**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>0 ± 0.2</td>
<td>(0.0)</td>
<td>0 ± 0.2</td>
<td>(0.0)</td>
</tr>
<tr>
<td>Dead</td>
<td>0 ± 0.4</td>
<td>(0.0)</td>
<td>0 ± 0.4</td>
<td>(0.0)</td>
</tr>
</tbody>
</table>

**Holcus lanatus**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>33 ± 15.3</td>
<td>(0.8)</td>
<td>21 ± 10.4</td>
<td>(0.6)</td>
</tr>
<tr>
<td>Dead</td>
<td>49 ± 21.0</td>
<td>(1.3)</td>
<td>46 ± 19.7</td>
<td>(1.3)</td>
</tr>
</tbody>
</table>

Introduced grasses (C4)

**Paspalum dilatatum**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>16 ± 11.6</td>
<td>(0.4)</td>
<td>9 ± 6.6</td>
<td>(0.3)</td>
</tr>
<tr>
<td>Dead</td>
<td>4 ± 4.7</td>
<td>(0.2)</td>
<td>6 ± 4.2</td>
<td>(0.2)</td>
</tr>
</tbody>
</table>

Other monocotyledons (introduced)

**Juncus spp.**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>9 ± 4.7</td>
<td>(0.2)</td>
<td>9 ± 4.7</td>
<td>(0.2)</td>
</tr>
<tr>
<td>Dead</td>
<td>56 ± 35.5</td>
<td>(1.4)</td>
<td>56 ± 35.5</td>
<td>(1.6)</td>
</tr>
</tbody>
</table>

**Asphodelus fistulosus**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>0 ± 0.0</td>
<td>(0.0)</td>
<td>0 ± 0.0</td>
<td>(0.0)</td>
</tr>
<tr>
<td>Dead</td>
<td>0 ± 0.0</td>
<td>(0.0)</td>
<td>0 ± 0.0</td>
<td>(0.0)</td>
</tr>
</tbody>
</table>

Forbs (introduced)

**Hypochoeris radicata**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>33 ± 3.7</td>
<td>(0.9)</td>
<td>16 ± 1.8**</td>
<td>(0.5)</td>
</tr>
<tr>
<td>Dead</td>
<td>77 ± 9.6</td>
<td>(2.0)</td>
<td>65 ± 8.0</td>
<td>(1.9)</td>
</tr>
</tbody>
</table>

**Acetosella vulgaris**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>(Proportion of pasture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>9 ± 3.6</td>
<td>(0.2)</td>
<td>6 ± 2.8</td>
<td>(0.2)</td>
</tr>
<tr>
<td>Dead</td>
<td>12 ± 4.7</td>
<td>(0.3)</td>
<td>11 ± 4.7</td>
<td>(0.3)</td>
</tr>
</tbody>
</table>

A superscript in the post-grazing column indicates a significant difference over time * (p < 0.05); ** (p < 0.001
Table 7.11. Average (± SE) biomass and the proportion the species contributed to the pasture of areas of high- and low-utilisation within the CG treatment and the physiological developmental stage of each plant species.

<table>
<thead>
<tr>
<th></th>
<th>High utilisation</th>
<th>Low utilisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(kg DM/ha)</td>
<td>(kg DM/ha)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1902 ± 182.5</td>
<td>1356 ± 151.6</td>
</tr>
<tr>
<td><strong>Green</strong></td>
<td>817 ± 75.6</td>
<td>324 ± 58.2</td>
</tr>
<tr>
<td><strong>Litter</strong></td>
<td>112 ± 8.1</td>
<td>410 ± 58.5</td>
</tr>
<tr>
<td><strong>Cover (%)</strong></td>
<td>97 ± 0.9</td>
<td>86 ± 2.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Native grasses (C3)</th>
<th>Herbage mass (kg DM/ha)</th>
<th>Developmental stage</th>
<th>Herbage mass (kg DM/ha)</th>
<th>Developmental stage</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Microlaena stipoides</em></td>
<td>528 ± 59.7</td>
<td>R</td>
<td>71 ± 48.4</td>
<td>R</td>
</tr>
<tr>
<td><em>Austrodanthonia spp.</em></td>
<td>17 ± 8.8</td>
<td>R</td>
<td>180 ± 41.7</td>
<td>R</td>
</tr>
<tr>
<td><em>Austrostipa spp.</em></td>
<td>1 ± 1.1</td>
<td>Sc</td>
<td>0 ± 0.0</td>
<td>Sc</td>
</tr>
<tr>
<td><em>Elymus scaber</em></td>
<td>0 ± 0.0</td>
<td>Sc</td>
<td>0 ± 0.0</td>
<td>-</td>
</tr>
<tr>
<td>Introduced grasses (C3)</td>
<td>254 ± 45.6</td>
<td>R</td>
<td>0 ± 0.0</td>
<td>-</td>
</tr>
<tr>
<td><em>Holcus lanatus</em></td>
<td>12 ± 7.2</td>
<td>V</td>
<td>0 ± 0.2</td>
<td>V</td>
</tr>
<tr>
<td>Introduced grasses (C4)</td>
<td>15 ± 9.8</td>
<td>V</td>
<td>0 ± 0.2</td>
<td>V</td>
</tr>
<tr>
<td>Legume (introduced)</td>
<td>2 ± 0.5</td>
<td>R</td>
<td>0 ± 0.0</td>
<td>-</td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td>13 ± 9.4</td>
<td>V</td>
<td>16 ± 11.4</td>
<td>V</td>
</tr>
<tr>
<td><em>Acetosella vulgaris</em></td>
<td>1 ± 0.3</td>
<td>V</td>
<td>0 ± 0.3</td>
<td>V</td>
</tr>
</tbody>
</table>

7.3.2.2 Pasture quality

The quality of the green component of the pasture species and the available average green pasture for the RG and CG treatments are shown in Tables 7.12 and 7.13, respectively.

The ewes grazing within the RG treatment reduced the biomass of green *M. stipoides* (p < 0.05) and *H. radicata* (p < 0.001). The N content, ME and DOMD of these species together with green *H. lanatus* and *Acetosella vulgaris* were significantly higher (p < 0.001) than that of the average green pasture. The quality of *Austrostipa* spp. was consistently lower than the average green pasture for the examined parameters.
Table 7.12. Average (± SE) N content, DOMD and ME of green pasture species components and average green pasture for RG treatment in early autumn.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Plant species</th>
<th>N (%)</th>
<th>DOMD (%)</th>
<th>ME (MJ/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native grasses (C3)</td>
<td><em>Microlaena stipoides</em></td>
<td>2.9 ± 0.21&lt;sup&gt;b&lt;/sup&gt;</td>
<td>61 ± 0.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.3 ± 0.09&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td><em>Austrodanthonia spp.</em></td>
<td>2.8 ± 0.00&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>52 ± 0.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.5 ± 0.00&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td><em>Austrostipa spp.</em></td>
<td>1.5 ± 0.00&lt;sup&gt;ad&lt;/sup&gt;</td>
<td>41 ± 0.0&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5.2 ± 0.00&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Native grasses (C4)</td>
<td><em>Bothriochloa macra</em></td>
<td>1.3 ± 0.21&lt;sup&gt;d&lt;/sup&gt;</td>
<td>53 ± 3.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.7 ± 0.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Introduced grasses (C3)</td>
<td><em>Holcus lanatus</em></td>
<td>3.2 ± 0.00&lt;sup&gt;h&lt;/sup&gt;</td>
<td>69 ± 0.0&lt;sup&gt;ad&lt;/sup&gt;</td>
<td>11.0 ± 0.00&lt;sup&gt;h&lt;/sup&gt;</td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td><em>Hypochaeris radicata</em></td>
<td>2.6 ± 0.16&lt;sup&gt;c&lt;/sup&gt;</td>
<td>60 ± 1.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>9.2 ± 0.26&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td><em>Acetosella vulgaris</em></td>
<td>4.5 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>71 ± 4.0&lt;sup&gt;e&lt;/sup&gt;</td>
<td>11.4 ± 0.80&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Average green pasture</td>
<td></td>
<td>2.1 ± 0.15&lt;sup&gt;c&lt;/sup&gt;</td>
<td>54 ± 1.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.8 ± 0.22&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a-d</sup> values with a different superscript in the same column are significantly different (p < 0.001)

The green component of *Austrodanthonia* spp. was higher than the average green pasture, but similar to the average pasture in terms of DOMD and ME.

Within the HU area of the CG treatment the ewes selected green *M. stipoides*, *H. lanatus*, *H. radicata* and *Paspalum dilatatum*. The DOMD, ME and N content of green *M. stipoides* and *H. lanatus* was higher (p < 0.05) than the average green pasture within the area. However, green *P. dilatatum* had a similar N content, DOMD and ME (p > 0.05) to the average green pasture.

The N content of the average green pasture harvested from the CG treatment was higher (p < 0.05) than the average green pasture from the RG treatment. Similarly, the quality of green *M. stipoides* and *H. radicata* from the CG treatment were slightly higher (p > 0.05) than the same species harvested from the RG treatment.
Table 7.13. Average (± SE) N content, DOMD and ME of green pasture species components and average green pasture for CG treatment in early autumn. All species were harvested from the HU areas.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Plant species</th>
<th>N (%)</th>
<th>DOMD (%)</th>
<th>ME (MJ/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native grasses (C3)</td>
<td><em>Microlaena stipoides</em></td>
<td>3.5 ± 0.25&lt;sup&gt;b&lt;/sup&gt;</td>
<td>63 ± 1.7&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>9.8 ± 0.32&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Introduced grasses (C3)</td>
<td><em>Holcus lanatus</em></td>
<td>3.6 ± 0.35&lt;sup&gt;b&lt;/sup&gt;</td>
<td>66 ± 2.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.5 ± 0.45&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Introduced grasses (C4)</td>
<td><em>Paspalum dilatatum</em></td>
<td>2.6 ± 0.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>58 ± 1.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>8.7 ± 0.25&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td><em>Hypochaeris radicata</em></td>
<td>3.4 ± 0.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>66 ± 1.7&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>10.3 ± 0.34&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>HU Average green pasture</td>
<td></td>
<td>2.6 ± 0.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55 ± 2.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.2 ± 0.38&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>LU- Average green pasture</td>
<td></td>
<td>2.4 ± 0.69&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55 ± 3.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.2 ± 0.75&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a-c</sup> values with a different superscript in the same column are significantly different (p < 0.001)

7.3.2.3 Predicted diet quality of ewes

The predicted DM intake (GrazFeed®) of an individual ewe grazing within the CG and RG systems are shown in Table 7.14. The predicted CP, ME intake and daily live weight loss for CG ewes was greater than RG ewes. The GrazFeed® model predicted the animals within both grazing systems selected a diet with a DMD of 58%.

Table 7.14. Predicted dietary intake and quality of dry, not pregnant ewes in early autumn (GrazFeed®)

<table>
<thead>
<tr>
<th>Diet parameters</th>
<th>CG</th>
<th>RG</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM intake (kg/hd/d)</td>
<td>1.05</td>
<td>1.04</td>
</tr>
<tr>
<td>DM digestibility (%)</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>Crude protein (g/d)</td>
<td>126</td>
<td>114</td>
</tr>
<tr>
<td>ME intake (MJ/d)</td>
<td>8.3</td>
<td>8.2</td>
</tr>
<tr>
<td>Weight gain (g/d)</td>
<td>-99</td>
<td>-81</td>
</tr>
</tbody>
</table>

7.3.2.4 Estimated diet quality of ewes

The estimated OMD<sub>w</sub> of the diet of the CG ewes was higher (p < 0.001) for day 1, 3 and 4 of faecal sampling but similar (p > 0.05) to the RG ewes on day 2, 5 and 6 (Figure 7.4). The CG ewes consumed an average diet that was of greater OMD<sub>w</sub> (p < 0.001) than RG ewes (55% vs. 53%). The OMD<sub>w</sub> of the diet of both treatments appeared to increase over time and was of a similar value to the DMD predicted by GrazFeed® of 58%.

The estimated MEM of the diet of RG ewes was higher (p < 0.001) for each day of faecal sampling but similar (p > 0.05) to the CG ewes on day 2 (Figure 7.5). The RG
animals consumed an average diet of higher \( \text{ME}_M \) (\( p < 0.001 \)) than CG ewes (6.6 vs. 6.0). The predicted \( \text{ME}_M \) intake of CG and RG animals (based upon the GrazFeed\textsuperscript{®} predicted DM intakes) were 6.3 and 6.9 MJ/d, respectively. These values were not consistent with the predicted GrazFeed\textsuperscript{®} ME intake of CG animals of 8.3 MJ/d and RG ewes of 8.2 MJ/d.

Prior to entering the studied paddock all three replicates of the RG animals grazed paddocks located within a MPZ of the landscape and were moved to paddocks located in a HPZ in the landscape.

Figure 7.4. Average (± SE) \( \text{OMD}_W \) of the diet consumed by dry ewes grazing within differing grazing systems over six days in early autumn. CG (green); RG (blue)
Figure 7.5. Average (± SE) ME$_M$ of the diet consumed by dry ewes grazing within differing grazing systems over six days in early autumn. CG (green); RG (blue)

7.3.2.5 Animal activity

The proportion of time ewes within the RG and CG were engaged in active and inactive behaviour is shown in Table 7.15. The CG ewes spent a greater proportion (p < 0.001) of time in an inactive state than active state and a greater proportion (p < 0.05) of time inactive in comparison to RG ewes.

Table 7.15. Proportion of time (± SE) dry, not pregnant ewes managed within differing grazing systems spent in an active or inactive state.

<table>
<thead>
<tr>
<th></th>
<th>Active</th>
<th>Inactive</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG</td>
<td>0.34 ± 0.04$^a$</td>
<td>0.66 ± 0.04$^c$</td>
</tr>
<tr>
<td>RG</td>
<td>0.46 ± 0.03$^b$</td>
<td>0.54 ± 0.03$^c$</td>
</tr>
</tbody>
</table>

A different superscript in the same row or column indicates a significant difference $a$-$b$ ($p < 0.05$); $a$-$c$ ($p < 0.001$)

7.3.2.6 Animal live weight and BCS

The average live weight, BCS and change in weight over time of the ewes prior to and following the second study period (March 2011) are presented in Table 7.16.
The ewes within the CG treatment were of a higher body weight prior to (p < 0.05) and following (p < 0.05) the study period than RG ewes. The CG ewes were also of a higher BCS pre and post the study period (p < 0.05). There was no difference (p > 0.05) in live weight change over the study period; however, the trend towards weight loss for RG may be indicative of a significant weight loss over time.

**Table 7.16.** Average (± SE) ewe live weight, BCS and live weight change over the second study period in autumn (March 2011)

<table>
<thead>
<tr>
<th></th>
<th>Pre- study period</th>
<th>Post- study period</th>
<th>Live weight change (g/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Live weight (kg)</td>
<td>BCS</td>
<td>Live weight (kg)</td>
</tr>
<tr>
<td>CG</td>
<td>66 ± 2.0 a</td>
<td>3.5 ± 0.1 a</td>
<td>66 ± 1.9 a</td>
</tr>
<tr>
<td>RG</td>
<td>62 ± 1.0 b</td>
<td>2.9 ± 0.1 b</td>
<td>59 ± 1.4 b</td>
</tr>
</tbody>
</table>

*ab values in the same column with a different superscript are significantly different (p < 0.05)*

### 7.3.3 Average live weight and BCS over time

The average live weight adjusted for wool growth and BCS of ewes from the first weighing post-weaning to six weeks pre-partum (mid - December 2010 to July 2011) and the average live weight and BCS of lambs from the first weighing post-partum to weaning (August - September to mid - December 2010) are shown in Figure 7.6 and Figure 7.7, respectively.

The adjusted live weight of ewes managed within the CG system was heavier than ewes managed within the RG system at all time periods (p < 0.05 for December to February and May; p < 0.001 March, June and July). Similarly, the ewes managed within the CG system had higher BCS than ewes managed within the RG system (p < 0.001, except December 2010 where p < 0.05) although in May and July no difference was recorded (p > 0.05).
The birth weight of CG and RG lambs were not different (p > 0.05). However, the live weight of lambs managed within the CG system was consistently greater than lambs managed within the RG system at each time point until weaning (p < 0.001, with the exception of September where p < 0.05). The BCS of the CG lambs was consistently higher than RG lambs and most notably in September and December (p < 0.05).

**Figure 7.7.** Average (± SE) lamb live weight and BCS from birth (August - September 2010) to weaning (mid - December 2010). CG (green); RG (blue)
7.3.4 Intake regulation

7.3.4.1 Plant species, biomass and quality

The quantity of forage consumed from each of the plant species present in the studied paddocks varied with species and the quantity of available forage. To account for changes in pasture composition, quality and biomass the proportion of green DM consumed relative to the initial green to dead ratio of the pasture species within the RG treatment (for pasture species with greater than 40 kg DM/ha) was log-transformed (log green to dead ratio + 1) and analysed and is shown in Figure 7.8.

A strong, positive, linear relationship (p < 0.001) was identified between the initial green to dead ratio of forage of a species and the percentage of green herbage of a species consumed by the animals (y = 2.157-0.971/(1+0.323*x); adjusted R² value = 0.76). The relationship identified that a greater proportion of a species was consumed as the green to dead ratio of a species increased. A similar upwards linear trend (p > 0.05) was also identified between the DOMD of the green DM of pasture species and the proportion of green DM consumed.

7.3.4.2 Grazing time

The proportion of time the RG animals spent in active behaviours was similar for the two grazing periods. However, the CG dry, not pregnant ewes spent a greater proportion of time inactive (non-grazing) than active. The average green pasture quality of the HU and LU areas when the ewes were dry and not pregnant and grazed for a smaller proportion of time was greater (0.4 MJ/kg) than the average green pasture of the RG ewes.
7.4 Discussion

7.4.1 Methodology

The detailed study of the pasture enabled identification of the physiological stage of growth of the plant species within the pasture and its relationship to the plant species selected by the grazing animals. This information was then used to harvest plant material in a similar stage of development for wet chemistry and in vitro quality analysis. Hand-plucked pasture samples provided a greater understanding of nutrient quality of the species that may be influencing selection and intake of the animals in comparison to average pasture cuts alone. However, it must be acknowledged that the results of wet chemistry and in vitro analyses of hand-plucked pasture samples need to be interpreted with caution as they still may not be representative of the exact components of a species consumed by grazing animals (Gordon 1995; Ben Salem and
Papachristou 2005) or the nutritive value of the diets of free-ranging livestock (Coates 2000).

Chemical analysis of faeces has the potential as a non-invasive method of assessing the quality of the diet of grazing animals in an efficient, rapid and economic manner. However, a limitation of the method is the development of appropriate equations to assess the diet quality of grazing animals and caution must be exercised when interpreting the results of predictive equations. As discussed in Chapter 5, where the applicability of two equations to assess trends in the diet quality of ewes grazing the same native grassland was investigated, it was found diet OMD (OMDW) could be estimated from an equation developed by Wang et al. (2009) ($R^2 = 0.67$) and dietary ME (ME$_M$) could be estimated from the equation established by Mahipala et al. (2009) ($R^2 = 0.54$). However, the estimated diet qualities of the animals derived from faecal chemistry analyses in this study were far from simple. The higher ($p < 0.001$) OMD$_W$ of the diet of CG animals in comparison to RG animals, was not aligned with the higher ($p < 0.001$) estimated diet ME$_M$ of RG ewes in comparison to CG animals during both study periods. As OMD and ME of plants are typically linked, both results cannot equally reflect the animal’s diet quality over time. The estimated diet quality of the animals must be considered in light of the pasture species selected by the animals, the quality of the selected species and the animal’s live weight and BCS over time. As the estimated ME$_M$ values did not align with animal production, plant quality and GrazFeed® estimations the predictions are considered to be inaccurate and probably incorrect. As a consequence other measurements such as the predicted OMD$_W$, pasture species selection and quality will be the focus of further discussion.

7.4.2 Pastures

The selective grazing of lactating ewes with lambs resulted in a decline in the biomass of green *M. stipoides* and *H. radicata* ($p < 0.001$) and *Austrodanthonia* spp. ($p < 0.05$) as well as green *L. rigidum* and *T. subterraneum*. These species were of greater N content, DOMD and ME than the average green pasture. One exception was green *Austrodanthonia* spp. that was of lower quality than the average green pasture. A similar selection of this species (that was lower than the average green pasture) was also observed in dry ewes grazing within the same pasture during August - September of 2010 and February 2011 (Chapter 6). Whilst there appears to be some consistency in the selection of the lower quality species over time the aforementioned limitations of the
method of harvesting hand-plucked samples for quality analysis must also be acknowledged.

Diet selection of dry, non-pregnant ewes grazing in early autumn was similar to lactating ewes with lambs at the beginning of spring; the animals reduced the biomass of green *M. stipoides* \((p < 0.05)\) and *H. radicata* \((p < 0.001)\) and these species were of higher nutrient quality (N, DOMD and ME) than the average green pasture. The plants species and components selected by the animals were similar to the observed selection of dry ewes grazing small plots at the site during the same season (Chapter 6). The animals were highly selective and consistently selected the leafy green vegetative material within the pasture, similar to the selection recorded by Leigh and Holgate (1976), Arnold (1981) and Chen *et al.* (2002) in grazing sheep. The dry ewes in this study appeared to avoid *B. macra* and *Austrostipa* spp. that were in a reproductive and senescent stage of development, respectively and were of substantially lower quality (in particular N content) than the average green pasture.

The selection of the green, typically vegetative component of the pasture appears to be influenced in part by the initial green to dead ratio of forage of a plant species where a greater proportion of green herbage of a species was consumed as the initial green to dead ratio of forage increased. A similar positive trend was identified between the DOMD of green forage and the proportion of green herbage consumed of a pasture species. As animals cannot perceive nutrient content *per se* (Arnold 1981) the spatial arrangement of the plant parts may be one of numerous processes involved in the selection of grazing animals. The relationship between initial green to dead ratio and proportion of green DM consumed and the trend in DOMD and green forage consumption are similar to previous observations of animal selection within the same pasture in late winter (Chapter 6). In this study the selection of the animals appears to be influenced by the spatial arrangement of plant components within the pasture (Hodgson 1982) and varied over time depending upon the presence and availability of other plant components and species (Chen *et al.* 2002) that influenced the available herbage mass and intake rate potential of the animals (Dumont and Gordon 2003).

The ewes grazing within the CG treatment consistently selected green vegetative material of *M. stipoides*, *H. radicata* and *H. lanatus* during both study periods. Lactating ewes with lambs in late spring also selected green *L. rigidum* and *T. subterraneum* whereas dry, non-pregnant ewes in early autumn selected green *P.*
The species selected by the animals were in a vegetative state of development, had a high proportion of green leaf and were of greater nutritive quality than the average green pasture of both the HU and LU areas. The pastures within the identified HU areas were extensively grazed by the animals and selected plants within these areas appeared to be ‘maintained’ in a predominantly vegetative stage of development by frequent defoliation (Briske and Stuth 1982; Pierson and Scarnecchia 1987; Jensen et al. 1990) and over time may result in the establishment of grazing patterns (Bakker et al. 1983), patches and grazing lawns (McNaughton 1984) within the pasture. Frequent grazing of a plant can increase the quality of the plant as a consequence of a higher proportion of young plant tissue with a high soluble carbohydrate to structural carbohydrate ratio (Walker et al. 1989). In contrast, grazing followed by extended periods of rest allows herbage accumulation (Chapman et al. 2003) as well as the maturation and subsequent decline in forage quality (Denny and Barnes 1977). The maintenance of the species in a vegetative state of development within the CG treatment is consistent with the higher (p < 0.05) N content of the average green pasture in comparison to same pasture from the RG treatment during the second grazing period in early autumn and the consistently higher quality of pasture species collected from within the HU area of the CG treatment across both studies.

Regardless of grazing treatment and physiological state ewes consistently selected green, vegetative species and components from the pasture that were of relatively high nutritive value. Furthermore, the animals appeared to avoid the consumption of plant species and components that were of lower quality and presumably lower palatability and are consistent with the high degree of selectivity of grazing sheep of forage that is typically highly digestible and palatable (Grimes et al. 1966; Leigh and Holgate 1978; Arnold 1981; Chen et al. 2002).

### 7.4.3 Animal activity

Lactating ewes and lambs within both grazing treatments spent a similar (p > 0.05) proportion of time in an active and inactive state. The proportion of time the animals spent in an active state is likely to be an effect of the animals’ high nutrient requirements associated with lactation (Parsons et al. 1994). The ewes were grazing to the maximum time expected of approximately 12 h (Penning et al. 1993) yet they were still losing weight indicating their nutrient requirements were not being met. The grazing time limit is presumably related to gut fill, which means in these circumstances
the animals cannot keep eating to the point where their lactation energy requirements are satisfied.

In early autumn the dry RG ewes spent a similar amount of time active in comparison to the previous study, and a greater \( p < 0.05 \) proportion of their time active compared to the CG ewes. Dry CG ewes spent a greater proportion \( p < 0.001 \) of their time inactive than active and substantially less time active \( p < 0.05 \) in comparison to the previous study period when the ewes were lactating with lambs at foot. The reduction in grazing time of the CG ewes is thought to be a result of the lower nutrient requirements of the dry animals and may also be associated with the higher average pasture quality (0.4 MJ/kg DM greater than RG) of the pasture during early autumn. The greater activity of the RG animals in comparison to CG animals is in contrast to studies by Le Du et al. (1979); Baker et al. (1981); Walton et al. (1981); Heitschmidt et al. (1987a; 1987b) in sheep and Walker and Heitschmidt (1989) in cattle and observations by Jamieson and Hodgson (1979) in sheep and cattle. The observed reduction in the grazing time of RG animals by the previous authors has been described as a response to the progressive defoliation of herbage and decline in herbage biomass together with a conditioned response by the animals to movement within a grazing system (Jamieson and Hodgson 1979). The extended activity of the RG animals observed in this study may be a consequence of the time required for the animals to select green vegetative material from the pasture that compromised a lower proportion of herbage than previously. The extended activity may also be attributed to the short duration and moderate intensity of grazing during the two study periods that resulted in approximately 37% of green DM being consumed and consequently no substantial reduction to the animal’s intake. Furthermore, the extended activity of the RG animals may also be a result of exploratory behaviour by the animals that has been recorded in sheep and cattle during the first two days of grazing a new paddock within a RG system (Arnold and Dudzinski 1978; Gluesing and Balph 1980). Activity of the animals can have important effects on animal production.

### 7.4.4 Animal production

The live weight of lactating ewes across both treatments decreased over the study period, which was expected due to milk production and the associated high nutrient requirements and the pasture quality in terms of ME was relatively low. The animals’ decline in body weight mirrored lamb live weight gain. The ewes and lambs within the
CG treatment had greater (p < 0.05) live weights and BCS pre and post the study and the CG lambs had a higher (p < 0.05) weight gain over the study period. The lactating ewes similarly lost condition over the study period and it is proposed the differences in lamb growth rate may be a consequence of differences in pasture intake (that was predicted to be slightly higher in CG lambs than RG lambs) and the resultant greater milk production of the CG ewes (Thompson et al. 2011a). Further examination of milk production and quality as well as the DM intake of ewes grazing within contrasting grazing systems is recommended.

During the second study CG ewes had higher (p < 0.05) pre- and post-live weights and BCS than RG ewes and the CG ewes loss less weight (p > 0.05) over the study period. However, changes in live weight over the short duration of the study period may be influenced by the time of day (of weighing), gut-fill effects and previous nutrition. Over time (December 2010 to mid-July 2011) ewes managed within the CG system were heavier (p < 0.001) and had higher BCS (p < 0.001) than RG ewes. Similarly, lambs managed within the CG system were heavier (p < 0.001) and had higher BCS (p < 0.05) than RG lambs. The number of lambs per ha was greater (p < 0.05) within the RG system that may have influenced the differences in growth rate between the systems. However, the differences in animal production between the systems cannot simply be attributed to SR as SR were not excessive or ‘limiting’ and similar differences in BCS were witnessed, in April and May 2008 when the SR of treatments were the same (Badgery unpub. data). Furthermore, the green herbage mass was higher post grazing in RG than the average of the HU areas in the CG. The higher individual animal production of the CG system may be a consequence of differences in DM intake and quality. A further influencing factor may be environmental and social stresses that RG animals are exposed to including; limited access to shade and shelter from wind and rain, a higher concentration of animals within a smaller area and associated social interactions of animals in particular during lambing and lactation that may result in elevated stress levels and the recorded lower production of both ewes and lambs. These factors would interact with diet quality to produce the results found.

7.4.5 Diet quality
The results of the estimated diet quality of the animals were far from simple due the conflicting results of a higher (p < 0.001) OMD\textsubscript{w} of the diet of CG ewes in comparison to a higher (p < 0.001) ME\textsubscript{M} value of the RG ewes. The OMD\textsubscript{w} regression equation...
derived by Wang et al. (2009) included a broad data set (159 diets and 721 observations) together with nine forages of varied quality in terms of: DM (139-939 g/kg); OM (831-951 g/kg) and CP (74-256 g/kg). The \( \text{MEM} \) predictive equation derived by Mahipala et al. (2009) was based on a smaller data set and the feeding of tannin containing browse-species that may not be as applicable to the studied pasture as the forages used by Wang et al. (2009) and indicated by the higher correlation \( (R^2 = 0.67) \) of \( \text{OMD}_W \) with the calculated diet DMD of grazing ewes at the site in comparison to estimated \( \text{MEM} \) and calculated ME intake \( (R^2 = 0.54) \) (Chapter 5). The higher diet quality of CG ewes predicted from the \( \text{OMD}_W \) reflected the GrazFeed\textsuperscript{®} predicted DMD and the results support the greater animal performance of CG ewes (and lambs) over time and the higher quality of forage harvested from within the CG system, than the RG system. In contrast neither the trend nor absolute values of estimated \( \text{MEM} \) reflected the GrazFeed\textsuperscript{®} predicted ME intake of the animals supporting the view that the predictive equation developed by Wang et al. (2009) provides a more accurate estimation of the quality of the consumed diet within the native pastures at the study site. It is concluded the predictive ME equations established by Mahipala et al. (2009) are not applicable to the vegetation at the study site. Hence more emphasis is placed on the \( \text{OMD}_W \) estimates than on \( \text{MEM} \) as measures of diet quality.

7.4.6 Management implications and future recommendations

It must be acknowledged that the two study periods only provide a ‘snap shot’ of diet selection and quality as well as grazing behaviour of RG ewes (and lambs) grazing within a single production zone within the landscape; the MPZ is assumed to represent the average diet of these animals. The study was designed though to investigate diet selection when pasture conditions and animal physiological states were in contrast and they cover the range in conditions typically found through the year. The animals within both management systems consistently selected green vegetative forage from within the pasture and altered their selection of plant species seasonally. Similar to results reported by Sharrow and Kruegar (1979) grazing management did not affect lamb birth weight, although in contrast to their results the growth rate of lambs managed within the CG treatment was significantly higher at each weighing.

The management of animals within a CG system permits the unrestricted use of a landscape and allows animals to graze and re-graze preferred plants and maintain a high quality of forage, resulting in higher live weights and BCS. However, the grazing and
re-grazing of preferred plants and plants within a landscape can lead to the development of grazing patterns and the establishment of grazing lawns which at high SR can lead to overgrazing and landscape and pasture degradation (Trlica 1977; Bryant et al. 1989; Archer et al. 1993; Kemp et al. 2000; Asner et al. 2004; Dorrough et al. 2004a; 2004b). In contrast RG systems are designed to allow a more even distribution of grazing and nutrients within a landscape and the accumulation of a greater amount of forage (Sharrow 1983). Rest periods associated with RG allow the accumulation of herbage (Chapman et al. 2003) as well as the maturation and associated decline in forage quality over time (Denny and Barnes 1977). The accumulation and maturation of forage can potentially reduce animals’ ability to select the green vegetative material from older dead forage, potentially reducing DM intake and consequently compromising the diet quality and production of animals, as was observed in this study. Managing the animals’ grazing location within the landscape allows preferred pasture species an extended period of rest to recover from grazing; however, the cost of managing animals within a RG system appears to be individual animal performance. The slightly higher stocking rate may also be implicated in these differences, though as the available herbage mass was at or above the point where intake could be limited it is more likely to be a system effect. From this study it appeared the higher individual animal production of CG animals was a consequence of the animals’ higher diet quality and potentially greater DM intake.

The aim of the study was to understand more about how grazing systems function; however, from the results of this study it is not possible to draw a clear conclusion as to the best management of animals within a landscape as soils, pasture composition and production as well as climatic factors and production objectives vary significantly between producers and regions. A compromise in the management of animals suggested by Sharrow and Kruegar (1979) for a native grasslands such as used here that warrants further investigation is the implementation of a form of RG when animals have low nutrient requirements (or during the green feed period) when maintaining live weights is not critical and shifting towards a CG system as animal nutrient requirements increase (Sharrow and Kruegar 1979). It is recommended future work investigates the landscape use of continuous grazing animals to gain further understanding of how animals utilise a landscape and forage within the landscape. It is also recommended that future studies attempt to quantify the DM intake and diet quality of animals grazing within contrasting
grazing systems over time and the impact of different production zones on the diet quality and behaviour of RG animals. Producers may shift focus between animal production and pasture composition, depending on the state of their pastures and business requirements, and could adapt grazing management to achieve these goals.

7.5 Conclusion

Grazing sheep consistently select green vegetative plant material from within a pasture and the species selected varies seasonally as the mechanisms underlying this selection appear in part to be related to the initial green to dead ratio of forage of plant species, DOMD and the spatial arrangement of plant components within a pasture.

The best indicator of the quality of the diet consumed by grazing sheep within the studied pasture appears to be the OMD predictive equation developed by Wang et al. (2009). However, the conflicting results provided by the ‘generic’ predictive equations highlight the need for further investigation of the applicability of these (and other) equations to different forages and regions. The potential development of global predictive equations relies upon cooperation between international research groups in order to address the immense challenge that determining the diet selection of animals grazing within heterogeneous landscapes remains for researchers and producers alike.

Managing the location and duration of grazing animals within a landscape through the implementation of a RG system resulted in lower per head animal production, pasture quality and estimated diet quality of grazing ewes in comparison to ‘free-ranging’ CG animals. However, the SR and per hectare production of the RG system was greater than the CG management. The higher production of CG animals may in part be a consequence of the animals’ maintaining areas of high quality pasture and potentially greater DM intake. A greater understanding of how grazing systems work and animals utilise a landscape and forage within a landscape is essential to enhance the management and production of grazing animals.
Chapter 8. Landscape Use by Sheep Grazing Within Native Pastures

8.1 Introduction

Grazed vegetation communities are heterogeneous in time and space (Chapman et al. 2007) and affect the landscape use and location of grazing animals. Spatially diverse landscapes together with the diet selectivity of sheep result in the uneven use of a landscape by grazing sheep and as a consequence the uneven distribution of nutrients within the landscape that can have a profound effect on sward composition and production (Adler et al. 2001; Soder et al. 2007; Oom et al. 2008). Unmanaged livestock within landscapes have been found to establish patterns of use and non-use (Willms et al. 1988; Ganskopp and Bohnert 2006) that can result in an increase in pasture quality in some patches together with the loss of preferred plant species and a decline in pasture quality in others (Mott 1987; Fuls 1992; Norton 1998).

The distribution of animals within a landscape and the location and duration of grazing have been associated with animal attributes as well as multiple vegetation and landscape effects. Animal factors that may affect distribution include species or breed of animal (Putfarken et al. 2008), need for escape or cover from predators (Stuth 1991), previous experience of a landscape (Bailey et al. 1996; 2004), reproductive status (Bailey et al. 2001) and social interactions (Penning et al. 1993; Dumont and Boissy 2000; Boissy and Dumont 2002). The location of an animal’s grazing may also be influenced by aspect, camping behaviour and position together with vegetation characteristics. Vegetation characteristics that have been found to affect the location and behaviour of grazing animals include species composition (Illius et al. 1992), forage quality, plant morphology and height (Bailey et al. 1996), plant productivity (Hodgson, 1985; Bailey et al. 1996) as well as the distribution of preferred plant species (Illius et al. 1992; Clarke et al. 1995; Edwards et al. 1996; Dumont et al. 2000; 2002; Ganskopp and Bohnert 2006) and non-preferred plant species (Wang et al. 2010a). An animal’s choice of grazing location is also affected by: the landscape, topography and slope (Valentine 1947; Baumont et al. 2000; Bailey et al. 2004; Thomas et al. 2008) that determine microclimate effects, predation risk and plant growth (Coughenour 1991) as well as proximity to water (Valentine 1947; Squires 1976; Baumont et al. 2000; Bailey et al. 2004; Thomas et al. 2008) and shelter (Taylor et al. 1987; Baumont et al. 2000; Taylor et al. 2011).
The complex interactions between plants and animals and landscape use of grazing animals has been previously described by Senft et al. (1987) and Bailey et al. (1996) using hierarchical models and relationships. They proposed grazing location is influenced by an animal’s preference for areas of high forage quality and quantity (Kenney and Black 1984) that is modified by visual cues (Bazley 1990) together with an animal’s memory and learning (Edwards et al. 1997; Dumont and Petit 1998). The movement of animals between locations within a landscape has been associated with forage depletion at the grazing site. This has been described by Charnov (1976) as the marginal value theorem and validated by Demment et al. (1993) and Laca et al. (1993) in cattle.

The interactions between grazing herbivores and plants are inherently complex and the effects of landscape variability and vegetation diversity on animal grazing behaviour are not well understood (Soder et al. 2007). A greater understanding of the landscape use of grazing animals within native pastures is essential to the use of grazing as a low-cost management ‘tool’ and in assisting livestock producers to make informed decisions about livestock management and the implementation of grazing systems within these complex pastures.

Essential to a greater understanding of behaviour and landscape use of grazing animals are methods that do not interfere with the normal grazing behaviour of the animals. A greater understanding of the location of animal grazing and the influence of landscape and vegetation has been explored via the use of GPS collars in sheep (Rutter et al. 1997; Oom et al. 2008; Umstätter et al. 2008; Taylor et al. 2011) and cattle (Bailey et al. 2004; Schlect et al. 2004; Ganskopp and Bohnert 2006; 2009; Putfarken et al. 2008; Handcock et al. 2009). Animal location data together with studies of animal behaviour (Umstätter et al. 2008; Ganskopp and Bohnert 2009; Handcock et al. 2009) and the use of landscape and vegetation maps using manual surveys and GIS data and/or satellite remote sensing using NDVI (Tucker et al. 1986) have expanded knowledge of the landscape use of grazing ruminants.

The primary aim of this study was to gain a greater understanding of the landscape use of ewes grazing a native grassland within the Central Tablelands of NSW and managed within a CG system. A second aim (from Chapter 7) was to examine if the grazing location of ewes was primarily based on the green to dead ratio of DM and/or the quality of the pasture species. The study involved ewes at different physiological states
(lactating with lambs at foot or when dry and not pregnant) and the use of GPS tracking of animals and manual vegetation assessments. It was hypothesised the distribution of the animals within the landscape would be uneven and grazing associated with the HPZ and pasture areas and species of high nutritive value.

8.2 Materials and methods

8.2.1 Experiment location and management
The experiment was conducted at the EverGraze Central Tablelands Proof Site, at Panuara in NSW over two time periods. The first was at the end of spring (18\textsuperscript{th} November to 8\textsuperscript{th} December 2010) when ewes were with lambs and lactating and the second period was in early autumn (2\textsuperscript{nd} to 22\textsuperscript{nd} March 2011), following weaning when ewes were dry and not pregnant. The experiment involved ewes managed within the three replicates of the continuous grazing (CG) treatment. This treatment was used because animals had more opportunities to selectively graze \textit{i.e.} exhibit more choice, than in the RG treatment. The plots were larger and hence landscape effects were more likely to be discerned.

Refer to Chapter 3, section 3.1 for further detail of the experiment location and management including geology, landscape and soil (section 3.1.2), general vegetation (section 3.1.3) and the site management and monitoring (section 3.1.4.2).

8.2.1.1 Climatic data
The climatic data for the experimental periods have been previously reported in Chapter 7, section 7.2.1.1 and Figure 7.1. The average daily temperature for the first grazing period in November - December 2010 and the second study period in March 2011 was 17°C. The total rainfall during the first and second grazing periods was 20 mm and 34 mm, respectively.

8.2.2 Geography and landscape
The landscape of the site is highly variable with an average elevation of 845 m (range: 820-870 m) and soils of varying depth and fertility. Soil fertility and topography at the site have been found to considerably influence land productivity. Prior to the commencement of the EverGraze experiment the site was mapped into three production zones: high, medium and low to describe this variability (refer to Chapter 3, sections 3.1.1 and 3.1.2, Figure 3.2 and Table 3.1). High production zones dominate the valley
floors and lower slopes and consist primarily of high quality and introduced pasture species. Mid-slopes support a complex mix of native, naturalised and some introduced species and are classified as MPZ. Whilst the upper slopes and ridges with soils of lower fertility are LPZ and are comprised of mainly native or naturalised pastures (Badgery, unpub. data). As a consequence of landscape variability each replicate was examined as an individual site, within the two study periods. Replicate 1 was predominantly east facing and had the lowest variation in elevation, lowest soil P (Bray test, Rayment and Higginson (1992) test 9E2) levels and the greatest diversity of pasture species of the replicates. Replicate 2, situated to the south of the site contained contrasting north and south facing slopes and Replicate 3, positioned to the north of the site contained the greatest variation in elevation of the replicates. Different areas of shade and shelter were available within each studied replicate (refer to Chapter 3, Figure 3.2).

8.2.3 Animals
The Merino ewes were approximately 5 years of age during the two study periods.
Refer to Chapter 3, section 3.1 for further information on the management of animals at the site (section 3.1.4.2) and during the study period (section 3.2.2).

8.2.4 Stocking rate
Each replicate had different numbers of ewes (and lambs) based upon FOO that varied through the year. Ewe numbers were adjusted after weaning and at scanning (in June) to achieve similar levels of herbage mass in each plot. Stocking rate was varied by the timing of when lambs were removed from the systems. The removal of lambs was based on the amount of FOO, whether lambs reached a target weight (42 kg) or average growth rate fell below < 100 g/hd/d.

The average (± SE) annual SR for the studied treatment (CG) was 6.1 (± 0.53) DSE/ha (50 kg ewe weight). The SR of the animals within the treatment during the first study period in November-December 2010 when ewes were lactating with lambs at foot was 14 (±1.4) DSE/ha and was 6.1 (±0.1) DSE/ha during the second grazing period following weaning when the ewes were dry and not pregnant.

8.2.5 Pasture biomass and composition
The vegetation biomass and composition was assessed at 60 permanent points within each replicate plot prior to the commencement of the two study periods according to the
site management protocols using BOTANAL (t‘Mannetje and Haydock 1963; Jones and Hargreaves 1979; Tothill et al. 1992). Each of the permanent points had been previously located using a GPS receiver. The location of pasture species in the landscape was typically associated with the three identified production zones outlined previously in section 8.2.2 and Chapter 3, Table 3.1. (refer to Chapter 3, section 3.1.1 and 3.1.2 for further details).

8.2.6 GPS tracking and grazing behaviour
During each replicate study GPS collars (Blue Telemetry Ltd, Scotland) were fitted to four randomly selected ewes. Positions were recorded every 15 s and included the date, time, latitude, longitude, temperature and satellite number. Motion sensors within the collars recorded the location of the animal’s head as four tilt values (maximum roll, minimum roll, maximum pitch, and minimum pitch). Refer to Chapter 3, section 3.4 for a description of the relevant methods.

Technical problems were anticipated and it was recognised that data from all four collar deployments for each of the three replicates (12 in total) within each study period would not be available due to vagaries in signal transmissions in the hilly country at the site. Data from six collars was available for analysis from each study period (Rep 1 n = 3; Rep 2 n = 2 and Rep 3 n =1).

8.2.7 Derived factors

8.2.7.1 Animal activity
The behavioural activity of each animal was determined as either active (grazing, graze walking, walking with head down) or inactive (standing with head up, lying or sitting with head up, walking with head up), as described by Umstätter et al. (2008).

8.2.7.2 Time periods
The average activity of each ewe within each sampling day for each experiment was determined over 12 minute intervals based upon the time after midnight of each day. The derived time for each day was then partitioned into four subintervals of: 0500 to ≤ 0900 h; 0900 to ≤ 1500 h; 1500 to ≤ 2000 h and 2000 to ≤ 0500 h (including 0000 h) based upon a preliminary analysis of the data. The data was then used to analyse the daily activity of the ewes.
8.2.7.3 Landscape preference

The production zone each recorded animal position was located in was determined and a relative preference (RP) (Heady 1964) or landscape preference index (LPI) (Handcock et al. 2009) value was calculated. The LPI (or RP) value is the ratio of the proportion of GPS locations recorded in a production zone of the landscape relative to the percentage of area the production zone represented within a plot. The LPI value was calculated using the following equation (Handcock et al. 2009):

\[
\text{LPI value} = \frac{\text{proportion of time spent in area of interest}}{\text{proportion of the area of interest compared to the total area available}}
\]

A value of 1 indicates the animals were indifferent to the area or land class and used the area in proportion to the presence of the production zone within the plot. A value of less than or greater than 1 implies the area was avoided or favoured by the animals, respectively.

8.2.7.4 Animal location and vegetation sampling points

Each recorded location was associated with one of the 60 permanent vegetation sampling points within each plot using Pythagoras theorem to calculate the nearest Euclidean distance. The pasture characteristics at each vegetation point included; total DM (kg/DM/ha), green FOO (kg/DM/ha), percentage green (%), litter DM, groundcover (%) and the biomass of each plant species present was assessed. The total number of GPS recordings in each quadrat within each replicate for each study period was calculated. The number of recordings at each quadrat when the animals were active was subsequently calculated and log-transformed (log of the number of active observations + 1) in order to calculate a category of animal activity. The quadrats within each replicate were grouped into eight categories when the log-transformed data was rounded to the nearest integer. A score of 0 indicated no activity and a score of 7 was assigned to quadrats with the highest activity levels. Major pasture species were identified as a species that occurred within at least five quadrats (12%) within an experiment replicate. The biomass of each major species was calculated as a percentage of the total herbage mass at each quadrat. Prior to PCA of the pasture species and animal activity for the two experiments the adjusted average of the major species was
calculated as the average of the species over all quadrats within a replicate to remove replicate and ewe number effects.

8.2.8 Statistical analysis
All analyses were performed using the statistical computing software R (2009).

To examine the influence of biomass on the location and level of animal activity the variables of; DM, percentage green, green FOO, litter DM and groundcover percentage were log-transformed. Log-transformed data was then analysed using linear mixed model analyses and fixed effects terms that were not significant at the 0.05 level were progressively removed. An ANOVA was subsequently conducted to identify any significant effects of biomass variables.

To examine any effect of species composition on animal location and activity, PCA using a correlation matrix was performed using log-transformed activity and the adjusted average of the major pasture species data.

8.3 Results

8.3.1. Animal activity
The average proportion of time ewes were active over time is shown in Figure 8.1. The lactating ewes with lambs spent a greater proportion of time during the day active (0500 h to before 2000 h) in comparison the dry, not pregnant ewes. The dry, not pregnant ewes displayed two periods of activity in the morning (after 0500 h and before 1000 h) and afternoon (before 1500 h to before 2000 h). Similarly, the lactating ewes with lambs also recorded peaks of activity during these two time periods. The initial peak of grazing each day was associated with sunrise and the cessation of grazing coincided with sunset and the last light of each day.
Figure 8.1. Average proportion of ewes active over time. Lactating ewes with lambs at the end of spring (black); dry, not pregnant ewes in early autumn (red). Sunrise and sunset (vertical dotted lines) at the end of spring (blue) and in early autumn (green).

8.3.2. Landscape preference

The landscape preference of the animals was calculated for the four time periods. The average LPI values for lactating ewes with lambs and dry, not pregnant ewes are reported in Table 8.1 and Table 8.2, respectively.

During the first period of grazing each day (0500 to $\leq 0900$ h) the lactating ewes (and lambs) preferentially utilised the HPZ, were indifferent to the MPZ and avoided the LPZ. The animals then similarly utilised the landscape throughout the remainder of the day prior to displaying very strong selection for the HPZ (and avoidance of the LPZ) during the final period of grazing for the day (1500 to $\leq 2000$ h). At night (2000 to 0500 h) the animals avoided the LPZ and HPZ and actively selected the MPZ within the landscape.

Throughout the second grazing period (when the ewes were dry and not pregnant) the animals preferentially grazed within the HPZ and utilised the MPZ and LPZ in proportion to their distribution within the landscape during the first grazing period of each day (0500 to $\leq 0900$ h). During the day (when animals were engaged in less activity) and during the evening grazing period (1500 to $\leq 2000$ h) the animals utilised the production zones in proportion to the area they represented within the landscape.
However, at night (2000 to 0500 h) the animals actively selected the LPZ, proportionally utilised the MPZ and stayed away from the HPZ.

The use of the landscape by the animals during the day when they were inactive and ruminating may be related to the location of shade and the overall landscape use may be influenced by the biomass and species composition of the vegetation.

Table 8.1. Average landscape preference index values (± SE) for lactating ewes with lambs during four time periods in late spring.

<table>
<thead>
<tr>
<th>Time period</th>
<th>High production zone</th>
<th>Medium production zone</th>
<th>Low production zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>0500 to ≤ 0900 h</td>
<td>2.1 ± 1.10</td>
<td>1.0 ± 0.43</td>
<td>0.5 ± 0.39</td>
</tr>
<tr>
<td>0900 to ≤ 1500 h</td>
<td>1.1 ± 0.45</td>
<td>1.3 ± 0.40</td>
<td>0.8 ± 0.44</td>
</tr>
<tr>
<td>1500 to ≤ 2000 h</td>
<td>2.4 ± 0.90</td>
<td>0.8 ± 0.09</td>
<td>0.6 ± 0.36</td>
</tr>
<tr>
<td>2000 to 0500 h</td>
<td>0.3 ± 0.09</td>
<td>1.7 ± 0.09</td>
<td>0.3 ± 0.17</td>
</tr>
</tbody>
</table>

Table 8.2. Average landscape preference index values (± SE) for dry, not pregnant ewes during four time periods in early autumn.

<table>
<thead>
<tr>
<th>Time period</th>
<th>High production zone</th>
<th>Medium production zone</th>
<th>Low production zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>0500 to ≤ 0900 h</td>
<td>1.9 ± 1.24</td>
<td>0.9 ± 0.19</td>
<td>1.2 ± 0.65</td>
</tr>
<tr>
<td>0900 to ≤ 1500 h</td>
<td>1.2 ± 0.58</td>
<td>1.2 ± 0.37</td>
<td>0.9 ± 0.33</td>
</tr>
<tr>
<td>1500 to ≤ 2000 h</td>
<td>1.1 ± 0.51</td>
<td>1.0 ± 0.19</td>
<td>1.2 ± 0.49</td>
</tr>
<tr>
<td>2000 to 0500 h</td>
<td>0.0 ± 0.01</td>
<td>1.2 ± 0.22</td>
<td>3.2 ± 2.09</td>
</tr>
</tbody>
</table>

8.3.3. Vegetation effects

The influence of pasture biomass in terms of DM (kg/DM/ha), percentage green, green FOO (kg/DM/ha), litter DM (kg/DM/ha), groundcover (%) and plant species composition on animal location and activity were examined.

8.3.3.1 Biomass effects

The influence of pasture biomass variables on animal activity was examined using log-transformed data (log of average active +1) and linear mixed models. Animal activity during late spring and early autumn increased as the percentage green (p < 0.001) increased and animal activity decreased as litter DM (p < 0.05) increased and is shown in Figure 8.2 and 8.3, respectively. DM, green FOO and ground cover percentage did not have an effect (p > 0.05) on animal activity.

8.3.3.2 Pasture species effects

Analysis of any effects of pasture species on animal activity was investigated using PCA methods for each experiment.
8.3.3.2.1 Lactating ewes with lambs

A regression analysis was conducted of the average adjusted species (log-transformed) data and ewe activity when the ewes were lactating with lambs at the end of spring. The regression coefficients of the major pasture species are shown in Table 8.3. The location of ewe grazing was positively associated with *Trifolium subterraneum*, *Lolium rigidum* and *Microlaena stipoides* (p < 0.05) and negatively associated with *Austrodanthonia* spp., *Elymus scaber*, *Austrostipa* spp. and *Hypochaeris radicata* (p < 0.05).

To further examine any influences of species on animal activity a PCA analysis was completed and is shown in Figure 8.4, where the two PCA axes jointly explain 25% of the total variance (axis 1 = 16%, axis 2 = 9%). The bi-plot indicates that the activity of lactating ewes with lambs was positively correlated with *T. subterraneum*, *L. rigidum* and *M. stipoides* and to some extent negatively correlated with *Austrodanthonia* spp., *Austrostipa* spp., *E. scaber*, *Asphodelus fistulosus* and *Bothriochloa macra*.

**Figure 8.2.** Relationship between the percentage green of the pasture and the level of animal activity for each replicate. a) Lactating ewes with lambs b) Dry and not pregnant ewes.
**Figure 8.3.** Relationship between the litter DM of the pasture and the level of animal activity for each replicate. a) Lactating ewes with lambs b) Dry and not pregnant ewes.

**Table 8.3.** Regression parameters between ewe activity and average adjusted plant species (log-transformed) when the ewes were lactating with lambs at foot in late spring.

<table>
<thead>
<tr>
<th>Pasture species</th>
<th>Regression coefficients</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native grasses (C3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austrodanthonia spp.</td>
<td>-2.91</td>
<td>0.005</td>
</tr>
<tr>
<td>Austrostipa spp.</td>
<td>-1.89</td>
<td>0.049</td>
</tr>
<tr>
<td>Elymus scaber</td>
<td>-3.18</td>
<td>0.019</td>
</tr>
<tr>
<td>Microlaena stipoides</td>
<td>3.42</td>
<td>0.035</td>
</tr>
<tr>
<td>Native grasses (C4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bothriochloa macra</td>
<td>-2.46</td>
<td>ns</td>
</tr>
<tr>
<td>Introduced grasses (C3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bromus hordeaceus</td>
<td>0.67</td>
<td>ns</td>
</tr>
<tr>
<td>Holcus lanatus</td>
<td>0.88</td>
<td>ns</td>
</tr>
<tr>
<td>Lolium rigidum</td>
<td>3.26</td>
<td>0.035</td>
</tr>
<tr>
<td>Vulpia spp.</td>
<td>2.65</td>
<td>ns</td>
</tr>
<tr>
<td>Other monocotyledons (introduced)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphodelus fistulosus</td>
<td>-1.67</td>
<td>ns</td>
</tr>
<tr>
<td>Legume (introduced)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trifolium subterraneum</td>
<td>3.73</td>
<td>0.011</td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetasella vulgaris</td>
<td>0.94</td>
<td>ns</td>
</tr>
<tr>
<td>Hypochaeris radicata</td>
<td>-2.60</td>
<td>0.022</td>
</tr>
</tbody>
</table>
Figure 8.4. Ordination diagram of animal activity and the major pasture species (occurring within at least 5 quadrats within a replicate) when the ewes were lactating with lambs in late spring. Each point represents a quadrat from Replicate 1 (dark blue); Replicate 2 (medium blue); Replicate 3 (light blue). Axis scores for species and activity have been plotted as vectors.

8.3.3.2.2 Dry, not pregnant ewes

A regression analysis was conducted of the average adjusted species (log-transformed) data and ewe activity when the ewes were dry and not pregnant in early autumn. The regression coefficients of the major pasture species are shown in Table 8.4. The location of ewe grazing was positively associated with *Paspalum dilatatum, Holcus lanatus* and *M. stipoides* ($p < 0.05$) and while there was no statistically significant negative associations, there were negative trends with *Austrostipa* spp., *E. scaber, Juncus* spp. and *Austrodanthonia* spp. ($p > 0.05$).

To further examine any influences of species on animal activity a PCA analysis was completed and is shown in Figure 8.5, where the two PCA axes jointly explain approximately 29% of the total variance (axis 1 = 17%, axis 2 = 12%). The bi-plot indicates that the activity of dry, not pregnant ewes was positively correlated with *P.*
dilatatum, H. lanatus and M. stipoides. A trend of decreasing activity was identified with increasing values of B. macra and E. scaber.

Table 8.4. Regression parameters between ewe activity and average adjusted plant species (log-transformed) when the ewes were dry and not pregnant in early autumn.

<table>
<thead>
<tr>
<th>Pasture species</th>
<th>Regression coefficients</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native grasses (C3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austrodanthonia spp.</td>
<td>-4.37</td>
<td>ns</td>
</tr>
<tr>
<td>Austrostipa spp.</td>
<td>-4.88</td>
<td>ns</td>
</tr>
<tr>
<td>Elymus scaber</td>
<td>-4.37</td>
<td>ns</td>
</tr>
<tr>
<td>Microlaena stipoides</td>
<td>1.47</td>
<td>0.035</td>
</tr>
<tr>
<td>Native grasses (C4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bothriochloa macra</td>
<td>-4.12</td>
<td>ns</td>
</tr>
<tr>
<td>Introduced grasses (C3)</td>
<td>Holcus lanatus</td>
<td>2.16</td>
</tr>
<tr>
<td>Introduced grasses (C4)</td>
<td>Panicum spp</td>
<td>3.01</td>
</tr>
<tr>
<td>Paspalum dilatatum</td>
<td>2.55</td>
<td>0.026</td>
</tr>
<tr>
<td>Other monocotyledons (introduced)</td>
<td>Juncus spp</td>
<td>-4.66</td>
</tr>
<tr>
<td>Forbs (introduced)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetosella vulgaris</td>
<td>-1.22</td>
<td>ns</td>
</tr>
<tr>
<td>Hypochaeris radicata</td>
<td>1.17</td>
<td>ns</td>
</tr>
</tbody>
</table>

Figure 8.5. Ordination diagram of animal activity and the major pasture species (occurring within at least 5 quadrats within a replicate) when the ewes were dry and not pregnant in early autumn. Each point represents a quadrat from Replicate 1 (dark blue); Replicate 2 (medium blue); Replicate 3 (light blue). Axis scores for species and activity have been plotted as vectors.
8.4 Discussion

In this study the animals were not evenly distributed across the landscape. The grazing location and activity of ewes in different physiological states was positively associated with the percentage green of DM within the landscape and grazing activity decreased as litter DM increased. During grazing the animals preferentially utilised the HPZ of the landscape (as well as the MPZ when lactating with lambs) and grazing location was positively associated with higher quality pasture species within the landscape. The animals avoided grazing within the LPZ and in late spring grazing was negatively associated with lower quality pasture species typically located within this production zone. The initiation and cessation of daily grazing was associated with sunrise and sunset, respectively during both study periods. The extended grazing activity of lactating ewes with lambs in comparison to dry, not pregnant is likely to be a result of the greater nutrient requirements of the lactating ewes together with the longer daylight hours of late spring.

The study highlighted the complex interactions between grazing animals, plants and landscape use that are affected by seasonal variations in day length and pasture composition as well as the physiological state of the animals. These results suggest that the use of GPS, pasture monitoring and GIS information provide a rapid and efficient means of collecting data and can assist in gaining a greater understanding of how animal utilise a landscape and the possible underlying mechanisms without the need for direct human intervention.

8.4.1. GPS data

Technical problems were anticipated with the GPS collars and it was recognised that data from all four collar deployments for each of the three replicates (12 in total) within each study period would not be available. The 50% failure rate of the collars recorded in this study was comparable to the failure rate of Wykoff et al. (2007) in feral pigs (swine) but greater than 15 - 29% recorded by Swanepoel et al. (2010) in leopards and the 20% failure rate observed by Sprague et al. (2004) in monkeys within a forest. The high failure rate within this study is likely to be a result of vagaries in signal transmissions in the hilly country at the site. However, despite these high failure rates the technology allows the study of animal behaviour and landscape use and minimises any influences of observers on animal behaviour and location.
8.4.2. Animal activity
The lactating ewes with lambs were more active than the dry ewes and commenced grazing earlier and ceased grazing later in the day. The greater activity (grazing time) of the lactating ewes in comparison to dry, non-pregnant ewes is consistent with the findings of previous studies that have compared the grazing time of dry and lactating ewes (Arnold and Dudzinski, 1967; Parsons et al. 1994; Penning et al. 1995). Extended grazing time of lactating animals is close to the maximum grazing time expected by sheep (Parsons et al. 1994) and is likely to be a response to the higher nutrient requirements associated with milk production. Longer grazing times of lactating animals have been observed to result in intakes 25 to 50% greater than dry, non-pregnant sheep (Penning et al. 1995) and cattle (Hutton 1963). The longer grazing activity of lactating ewes in this study may be associated with longer day light hours in early spring together with the higher nutrient requirements of lactating animals. Additionally, the timing and duration of grazing may be influenced by the seasonal effects of higher maximum and marginally higher minimum temperatures during late spring and early summer (Dudzinski and Arnold 1979; Arnold 1982; Taylor et al. 1987).

8.4.3. Landscape preference
The animals were not evenly distributed within the landscape and thus it is inferred vegetation was not evenly utilised nor were nutrients evenly distributed within the landscape. The lactating ewes with lambs when active (grazing) preferentially utilised the HPZ and MPZ and when inactive the animals favoured the MPZ within the landscape that may be the warmer part of the landscape at night. Dry, non-pregnant ewes preferentially made use of the HPZ when active and the LPZ when inactive. During both studies and all activity (active and inactive combined) the animals appeared to avoid the LPZ and similarly avoided the LPZ during activity. Conversely, during inactivity the animals avoided the HPZ within the landscape. The activity (grazing) of the animals appears to be positively linked with the areas of high production and higher quality pasture species within the landscape. The positive association of animal activity with landscape position potentially supports the positive relationships of the location of grazing animals within a landscape with: forage quality, plant productivity (Hodgson, 1985; Bailey et al. 1996); and the distribution of preferred plant species (Illius et al. 1992; Clarke et al. 1995; Edwards et al. 1996; Dumont et al. 2000; 2002; Ganskopp and
Bohnert 2006). Similarly, the use of lower productive areas including the mid- and upper-slopes and ridges during inactive (resting and rumination) may be associated with trees and shelter (Taylor et al. 1987; Baumont et al. 2000; Taylor et al. 2011), innate predation risk (Stuth 1991) and the distribution of non-preferred plant species (Wang et al. 2010a). The strong preference of the LPZ (3.7; p < 0.05) by dry, non-pregnant ewes is in part influenced by the greater proportion of time spent in inactive rather than active behaviours in comparison to lactating ewes with lambs. However, the greater use of these areas when inactive may have been influenced by the elevation and microclimates of these areas as the animals camped at the higher points (upper slopes and ridges) of the landscape similar to the behaviour of grazing sheep within the Northern Tablelands of NSW observed by Taylor et al. (1987). The establishment of sheep camps within a landscape that is typical of CG animals is associated with a high concentration of faeces and an uneven distribution of nutrients within the landscape that in turn influences vegetation and future use of the area (Bailey et al. 1996; 2004). The greater utilisation of the MPZ by lactating ewes in comparison to dry animals may have been influenced by the animal’s greater nutrient requirements as well as the available vegetation. The influence of vegetation on animal behaviour and activity is an important consideration that will now be discussed.

8.4.4. Vegetation effects

The animals’ location when active appeared to be associated with the percentage green of the pasture, whereby grazing activity increased as the percentage green of the pasture increased (p < 0.001). Equally, grazing activity decreased as litter DM increased (p < 0.05). Similar positive associations between the greenness of forage within a pasture and increasing frequency of animal use of the area have been observed in cattle grazing with GPS and correlated with NDVI values (Handcock et al. 2009). The positive correlation between landscape use and the proportion of green pasture is also associated with the higher LPI values of the MPZ and HPZ of lactating ewes with lambs and dry, not pregnant ewes, respectively. The HPZ and to a lesser degree MPZ are located lower in the landscape and are typically associated with greater soil moisture and nutrient flows within the landscape (Badgery, unpub. data). The LPZ within the landscape are associated with lower soil moisture, biomass and percentage of green biomass and thus lower animal grazing activity. The positive correlation between the percentage green of the pasture together with the effect of litter DM and animal location may in part be the
means by which animals select a grazing site or patch within the landscape according to the hierarchical models of Senft et al. (1987) and Bailey et al. (1996) prior to exerting plant species selection at the site.

The influence of plant species on animal location and activity varied seasonally and when the ewes were in different physiological states. The location and activity of lactating ewes with lambs was negatively influenced by a greater number of pasture species than when the ewes were dry and not pregnant. The differences may in part be explained by the greater activity of lactating ewes as well as the variation in developmental stage of the species between study periods, similar to the recorded differentiation of the selection of ewes grazing small plots at the site over time (Chapter 6). Within both experiments (and physiological states) the ewes selected the pasture species that were in a vegetative or early reproductive stage of development and were of higher quality (N, DOMD and ME) in comparison to the average green pasture of hand-plucked samples analysed using wet chemistry and \textit{in vitro} analyses (reported in Chapter 7). The selected vegetation were generally located within the HPZ and MPZ of the landscape and associated with areas of higher soil moisture and high quality neighbouring plants (Rousset and Lepart 2002). The pasture species that were negatively correlated with grazing when the ewes were lactating (\textit{Austrodanthonia} spp., \textit{Austrostipa} spp., \textit{E. scaber}, \textit{A. fistulosus} and \textit{B. macra}) were of lower nutritive value and typically located within areas of lower productivity. The negative association between grazing and \textit{H. radicata} when the ewes were lactating in late spring, was unexpected due to the observed active selection of the species by dry, not pregnant ewes in small plots (Chapters 5 and 6) and lactating ewes with lambs within the RG system (Chapter 7). The negative association may be a result of the species being distributed within the three production zones of the landscape and the observed selection of the species within areas of HU and LU that were located within the HPZ and LPZ of the landscape, respectively during the study.

8.4.5. Management implications

The use of GPS, pasture monitoring and GIS information provide a rapid and efficient means of collecting data that can enhance the understanding of grazing behaviour and landscape use.

Grazing sheep (and cattle) move around a landscape and preferentially select locations that may have a set of favoured attributes that typically result in spatial- and temporal-
patterns and relationships (Handcock et al. 2009). The selection of the LPZ during inactivity may be driven by the animals’ need for shelter (Thomas et al. 2008) and to reduce predation risk by resting at high areas within the landscape (Taylor et al. 1987; Baumont et al. 2000). Likewise, the selection of HPZ and MPZ during activity is in part influenced by vegetation characteristics, species composition (Illius et al. 1992), forage quality, plant morphology and height (Bailey et al. 1996), plant productivity (Hodgson, 1985; Bailey et al. 1996) as well as the distribution of preferred plant species (Illius et al. 1992; Clarke et al. 1995; Edwards et al. 1996; Dumont et al. 2000; 2002; Ganskopp and Bohnert 2006). The mechanisms underlying the landscape use of the animals are complex, inter-related and far from definitive. However, positive associations between the location and activity of the ewes, the production zones, the percentage of green pasture (or greenness of the pasture) and high quality pasture species were recorded in this experiment. These observations were similar to previous experiments at the site where the diet selection of ewes varied seasonally (Chapter 6), according to the available pasture (Chapter 5) and the quality of the pasture species (Chapters 5, 6 and 7). The variation in the use of the production zones by the animals supports the idea that fencing of landscapes should occur across slopes and productivity zones rather than the traditional fence lines that typically follow bearings (Dorrough et al. 2004a).

Restricting animals to areas within a landscape through the use of grazing management systems may result in a greater distribution of animal location and activity. However, restricting the location of the animals also restricts the animals’ access to preferred areas within the landscape during activity that include areas of high proportions of green feed, preferred plant species and the maintenance of plant species in (higher quality) vegetative states. The animals’ access to shelter and preferred camping areas are also restricted and these factors together with higher effective SR typically observed within RG systems may in part be related to the observed lower production of animals managed within the RG system at this study site (Chapters 4 and 7). Greater knowledge of the landscape use of grazing animals is essential to the improved management of animals within variable landscapes and in particular the enhanced production of animals within grazing management systems.

8.5 Conclusion

Landscape use by grazing animals is far from simple and is affected by the animal’s physiological state and nutrient requirements and the available pasture and topography.
The location and activity of grazing animals within the landscape was influenced by the production zones (that are associated with elevation and nutrients). Animal activity and location was consistently positively associated with high levels of percentage green or ‘greenness’ of the pasture and was influenced by the available pasture species that changed seasonally, supporting the results presented in Chapters 5 and 6. Restricting the location and activity of animals within a landscape will affect the activity and diet selection (and quality) of the animals. The use of GPS, pasture monitoring and GIS information provide a rapid and efficient means of collecting data and can assist in gaining a greater understanding of how animal utilise a landscape and the possible underlying mechanisms without direct human intervention. However, the need for a greater understanding of the behaviour, activity and selection of grazing animals is ongoing.
Chapter 9. Pasture Digestibility and Predicting the Diet Quality of Animals from Faecal Indices and fNIRS

9.1 Introduction

Sheep selection of plant species from within the native grassland of Central NSW appears to be primarily on the basis of green to dead DM ratio (Chapters 5 to 8) as well as the nutritive value of those species (Chapters 6 and 7).

Information about the nutritive value of native pastures is limited primarily to the studies of Archer and Robinson (1988) and Robinson and Archer (1988) of six native grass species in the Northern Tablelands of NSW. The authors found unselected native grasses such as *Microlaena stipoides* had a moderate to high nutritive value, depending upon growing conditions. But that work did not specifically evaluate the nutritive value of what animals were actually eating. Greater information about the nutritive value of these pastures in different regions and landscapes is important in the development of a greater understanding of animal performance within native pastures as well as an enhanced accuracy of estimating FOO and determining the nutritive value of the diet of sheep grazing within these native pastures.

Faecal (chemical) indices have successfully been used to predict the digestibility and/or nutritive value of the diet consumed by sheep (Wehausen 1995; Boval *et al*. 2003; Mahipala *et al*. 2009; Wang *et al*. 2009). Similarly, fNIRS have effectively predicted the digestibility and/or quality of the diet of sheep in studies by Li *et al*. (2007b), Fanchone *et al*. (2007; 2009), Decandia *et al*. (2009); Decruyenaere *et al*. (2009) and Kumara Mahipala *et al*. (2010). The use of faecal indices (Lukas *et al*. 2005) and fNIRS (Li *et al*. 2007b) to estimate the nutritive value of the diet has great potential in grazing animals as a non-invasive method of sampling large numbers of animals without the need for pasture samples provided effective predictive equations are available or developed. The use of faecal indices and fNIRS to estimate the nutritive value of the diet has not been applied to sheep consuming native pastures within the HRZ of south-eastern Australia.

In this chapter the *in vivo* digestibility of native pastures harvested from the study site in 2011 was examined. The development of a predictive model of the nutritional characteristics of the diet of an animal from faecal indices and fNIRS analyses was investigated. The suitability of potential ‘generic’ equations developed by Mahipala *et
al. (2009) and Wang et al. (2009) from faecal indices and the applicability of derived fNIRS predictive equations to the studied pasture were evaluated. It was hypothesised that predictive equations derived from faecal indices and fNIRS analyses could be used to predict the dietary OMD and ME of sheep within the feeding study.

9.2 Materials and methods

9.2.1 Forages for digestibility study
Native pasture was harvested from the Orange EverGraze Proof Site on four separate occasions to determine any changes in pasture quality over time. The pasture was harvested during January 2011 (Diet 1), March 2011 (Diet 2), May 2011 (Diet 3) and June 2011 (Diet 4) that resulted in regrowth periods of approximately 60 days for Diet 2 and 3 and 35 days for Diet 4. The pasture was harvested using a mechanical cutter and hand-collected from an unfertilised MPZ within the site. The area was dominated by Microlaena stipoides and Austrodanthonia spp. and contained varying quantities of Elymus scaber, Bothriochloa macra, Hypochaeris radicata, Lolium rigidum and Poa bulbosa. In January 2011 (Diet 1) M. stipoides and Austrodanthonia spp. were in a late vegetative and reproductive stage of development, respectively. The subsequent diets were comprised of pasture that was vegetative regrowth from the previous harvest. Due to the required quantity of pasture material the time to harvest the pasture was slower than ideal and may have resulted in a decline in forage quality, particularly in summer when temperatures were higher. Furthermore, as a result of the timing of harvest and the distance between the pasture and animal house the pasture was dried (at 60°C in a fan-forced oven for 48 h), the time between harvest and drying varied from 2 to 6 h. Following drying the pasture was stored in large nylon (wool-pack) bags at room temperature prior to transportation to the animal house.

9.2.2 Housing of sheep
The pen-feeding experiment was conducted at the NSW Department of Primary Industries (NSW DPI) nutrition facility in Wagga Wagga (35°2'S, 147°19' E), NSW. The use and care of animals was approved by the Charles Sturt University Animal Care and Ethics Committee (protocol number: 11/030).

The experimental period comprised a total of 17 days with a preliminary 10 day adaptation period during which the sheep were housed in individual pens, followed by a
7 day collection period, during which the sheep were housed in metabolism crates, which were fitted with appropriate faeces collection facilities.

9.2.3 Animals and feed allocation
Twenty four, dry Merino ewes were sourced from the same commercial flock grazing at the Charles Sturt University Farm in Wagga Wagga to ensure the animals had the same grazing background. All of the ewes were approximately 13 months of age with an average live weight of 40 (± 0.49) kg, BCS of 3. The ewes were weighed and then randomly allocated on a stratified weight basis to an individual pen and diet. There were no significant differences (p > 0.05) in live weights of the ewes between the treatment groups.

The animals were offered feed at a level equivalent to 2% of body weight (on a DM basis). The daily feed allocation was fed at 0900 h following the collection and weighing of feed refusals to determine daily feed intake. The animals had ad libitum access to fresh, clean water.

9.2.4 Pasture and faecal sample collection
Representative samples of each diet (0.5 kg) were collected prior to feeding the daily ration on every day of the collection period. Similarly, representative samples (15%) of feed refusals of individual sheep were collected following weighing of feed refusals. For the duration of the 7 day collection period the daily amount of total faeces voided by each animal was recorded and a representative sample (15%) of voided faeces was collected each day and stored frozen in sealed polythene bags at -18°C.

Composite samples for each sheep were made by mixing the collected feed samples to represent each diet. In the same way composite feed refusal and faecal samples were made to represent each sheep prior to drying in fan-forced oven (at 60°C for 48 h) to determine DM content. Dried samples were then ground using a hammer mill (1 mm screen) prior to chemical analysis.

9.2.5 Plant and faecal chemical analysis
Analyses of the diet (and feed refusals) and faeces included N, NDF, ADF and ash. Information relating to the analysis of the samples is found in Chapter 3, section 3.5.2.
The CP content of each diet was calculated \((N \times 6.25)\). The ME value of each pasture sample was estimated using the following prediction equation based on \textit{in vivo} digestibility (AFIA 2011):

\[
\text{ME (MJ/kg DM)} = 0.203 \times \text{DOMD (\%)} - 3.001.
\]

### 9.2.6 NIRS analysis and equation development

Prior to scanning the dried and ground faecal samples were placed in a desiccator for 1 h to equilibrate with ambient temperature. NIR spectra were obtained on a Brucker® MPA NIR spectrometer (Bruker Optik GmbH, Ettlingen, Germany) with a spectral range of 3600 µm to 12500 µm. NIR calibrations were optimised using OPUS (2006) software with faecal spectra subject to spectra reprocessing involving 11 separate methods and using defined optimisation regions of 12489 - 7500, 7500 – 6100, 6100 – 5450, 5450 – 4600 and 4600 – 4250 µm either singularly or in combination. Over 300 iterations were performed to provide the best optimisation based on lowest root mean square error of cross validation (RMSECV) and rank.

Final calibration equations were then developed and the precision of each equation was evaluated based in the coefficient of determination \((R^2)\), the standard error of calibration \((SEC)\) and the residual prediction deviation \((RPD)\). The dataset was not large enough for external validation and as a result the calibration was evaluated internally using eight samples and cross-validation.

### 9.2.7 Calculations

#### 9.2.7.1 Nutrient digestibility

The apparent digestibility of a food is most accurately defined as the proportion which is not excreted in faeces and therefore assumed to be absorbed by the animal. The digestion coefficient of each constituent (DM, OM, CP, NDF, ADF, and CP) was determined for the feed consumed as well as the faeces as follows:

\[
\text{Digestibility (\%)} = \left[\frac{\text{dietary intake (of the nutrient)} - \text{faecal output}}{\text{dietary intake}}\right] \times 100
\]

#### 9.2.8 Evaluation of faecal chemistry predictive equations

The OMD and ME of the diets consumed by the animals was compared to the \(\text{OMD}_M\) and \(\text{ME}_M\) values predicted by equations derived by Mahipala \textit{et al.} (2009) and \(\text{OMD}_W\) predicted by an equation developed by Wang \textit{et al.} (2009). The details of these equations are outlined in Chapter 3, section 6.2.
9.2.9 Statistical analysis

Treatments means for all parameters were analysed using ANOVA (Genstat\textsuperscript{®} 13\textsuperscript{th} edn, Hemel Hempstead United Kingdom) and differences were significant when p < 0.05.

The development of predictive models of dietary nutritional characteristics from faecal indices was examined by forward stepwise regression procedure (R version 2.10). Predictive models were considered to be significant when p < 0.05 with a precision level (R\textsuperscript{2}) of greater than 0.75.

The relationship between the ingested dietary OMD and ME of individual ewes and the estimated dietary OMD\textsubscript{M}, OMD\textsubscript{W}, and ME\textsubscript{M} values from predictive equations were analysed using regression analysis in Genstat. A significant relationship was identified when p < 0.05.

9.3 Results

9.3.1 Diet quality and animal intake

The nutritive values of the four diets are presented in Table 9.1. The calculated average DOMD and ME of all diets were 34\% and 3.8 MJ/ kg DM, respectively. The DOMD of Diets 2 and 4 were significantly (p < 0.001) lower than Diets 1 and 3. Similarly, the ME of Diets 2 and 4, which were harvested in autumn and winter, were lower (p < 0.001) than Diets 1 and 3 that were harvested in summer and late autumn, respectively. The average CP content of the diets was 80 g/kg DM, Diet 1 had the lowest CP content (69 g/kg DM) whilst Diet 4 had the highest CP content (89 g/kg DM). The average NDF, ADF and ash contents of the diets were 705, 147 and 79 g/kg DM, respectively.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DM (g/kg)</td>
<td>923</td>
<td>928</td>
<td>917</td>
<td>952</td>
</tr>
<tr>
<td>NDF (g/kg DM)</td>
<td>750</td>
<td>750</td>
<td>710</td>
<td>610</td>
</tr>
<tr>
<td>ADF (g/kg DM)</td>
<td>122</td>
<td>162</td>
<td>156</td>
<td>149</td>
</tr>
<tr>
<td>Ash (g/kg DM)</td>
<td>67</td>
<td>85</td>
<td>89</td>
<td>74</td>
</tr>
<tr>
<td>CP (g/kg DM)</td>
<td>69</td>
<td>84</td>
<td>78</td>
<td>89</td>
</tr>
<tr>
<td>DOMD (%)</td>
<td>38 ± 1.3\textsuperscript{a}</td>
<td>28 ± 1.3\textsuperscript{b}</td>
<td>37 ± 1.4\textsuperscript{a}</td>
<td>31 ± 1.3\textsuperscript{b}</td>
</tr>
<tr>
<td>ME (MJ/kg DM)</td>
<td>4.7</td>
<td>2.7</td>
<td>4.5</td>
<td>3.3</td>
</tr>
</tbody>
</table>

\textsuperscript{ab} values in the same row with a different superscript are significantly different (p < 0.001)
The average daily intake of DM, OM and CP of the animals are reported in Table 9.2. There was no difference (p > 0.05) between diets in terms of DM and OM intake and faecal output. However, the CP intake (g/d) of animals consuming Diet 1 was less than (p < 0.001) the animals consuming all other diets and the CP intake of ewes consuming Diet 4 was greater (p < 0.001) than all other diets. The differences in CP intake between the diets reflect the low and high CP content of Diet 1 and 4, respectively.

Table 9.2. Average (± SE) DM, OM and CP intake and faecal output of each dietary group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intake (g/d)</th>
<th>Diet 1 (n = 6)</th>
<th>Diet 2 (n = 6)</th>
<th>Diet 3 (n = 6)</th>
<th>Diet 4 (n = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM (g/day)</td>
<td></td>
<td>689 ± 21.7</td>
<td>637 ± 21.7</td>
<td>660 ± 23.8</td>
<td>665 ± 21.7</td>
</tr>
<tr>
<td>OM (g/day)</td>
<td></td>
<td>643 ± 20.0</td>
<td>583 ± 20.0</td>
<td>601 ± 21.9</td>
<td>615 ± 20.0</td>
</tr>
<tr>
<td>CP (g/day)</td>
<td></td>
<td>47 ± 1.7</td>
<td>53 ± 1.7</td>
<td>52 ± 1.9</td>
<td>59 ± 1.7</td>
</tr>
<tr>
<td>Faecal output (g/day)</td>
<td>375 ± 17.4</td>
<td>395 ± 14.2</td>
<td>349 ± 15.1</td>
<td>409 ± 9.4</td>
<td></td>
</tr>
</tbody>
</table>

*a-c values with a different superscript in the same row are significantly different (p < 0.05)

9.3.2 Chemical composition, digestibility and faecal indices predictive regression models

A summary of the chemical composition and digestibility results of the feeding experiment used to develop the predictive regression models are presented in Table 9.3. The multiple regression models predicting dietary attributes from faecal indices on a DM basis are reported in Table 9.4.

The significant (p < 0.05) models were identified and found to predict dietary ADF, OM and DMD. However, all of the models recorded very low R² values (0.44, 0.3 and 0.15, respectively) and were consequently deemed inaccurate.

Table 9.3. Chemical composition and digestibility results of feeding experiment used to develop the predictive regression models (n = 24)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Feed</th>
<th>Faecal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (± SE)</td>
<td>Min - Max</td>
</tr>
<tr>
<td>NDF (g/kg)</td>
<td>705 ± 33.0</td>
<td>610 - 750</td>
</tr>
<tr>
<td>ADF (g/kg)</td>
<td>147 ± 8.8</td>
<td>122 - 162</td>
</tr>
<tr>
<td>CP (g/kg)</td>
<td>80 ± 4.3</td>
<td>69 - 89</td>
</tr>
<tr>
<td>Ash (g/kg)</td>
<td>79 ± 5.0</td>
<td>67 - 89</td>
</tr>
</tbody>
</table>
Table 9.4. Multiple regression models predicting dietary characteristics from faecal indices.

<table>
<thead>
<tr>
<th>Feed property</th>
<th>Predictive model</th>
<th>p-value</th>
<th>$R^2$</th>
<th>RSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADF</td>
<td>$ADF = 15.1357 + 0.6989(f_{Ash}) - 1.2002(f_{CP})$</td>
<td>0.001</td>
<td>0.436</td>
<td>1.699</td>
</tr>
<tr>
<td>OM</td>
<td>$OM = 99.4067 - 0.4735(f_{Ash})$</td>
<td>0.004</td>
<td>0.300</td>
<td>1.421</td>
</tr>
<tr>
<td>DMD</td>
<td>$DMD = 46.4265 - 1.2081(f_{Ash})$</td>
<td>0.035</td>
<td>0.154</td>
<td>5.223</td>
</tr>
<tr>
<td>CP</td>
<td>$CP = 16.1141 - 0.9529(f_{CP})$</td>
<td>0.066</td>
<td>0.110</td>
<td>0.955</td>
</tr>
<tr>
<td>DOMD</td>
<td>$DOMD = 43.9773 - 0.8424(f_{Ash})$</td>
<td>0.111</td>
<td>0.074</td>
<td>4.903</td>
</tr>
<tr>
<td>ME</td>
<td>$ME = 5.9264 - 0.171(f_{Ash})$</td>
<td>0.111</td>
<td>0.995</td>
<td>0.075</td>
</tr>
<tr>
<td>NDF</td>
<td>$NDF = -30.8208 + 0.7898(f_{NDF}) + 5.7017(f_{CP})$</td>
<td>0.116</td>
<td>0.112</td>
<td>6.470</td>
</tr>
<tr>
<td>OMD</td>
<td>$OMD = 35.537$</td>
<td>-</td>
<td>-</td>
<td>5.162</td>
</tr>
</tbody>
</table>

9.3.3 Comparison of ingested and estimated diet quality parameters

The actual OMD of the consumed diet (i.e. feed offered minus feed refusals) was compared to the predicted OMD$_M$ and OMD$_W$ of the diet (Table 9.5) and the average ME of the consumed diet was compared to the predicted MEM (Table 9.6). The average OMD of the diet was less than ($p < 0.001$) the predicted values of OMD$_M$ and OMD$_W$. Similarly, the average ME of the diet was less than ($p < 0.001$) the predicted MEM.

Table 9.5. Average ($\pm$ SE) OMD and predicted OMD$_M$ and OMD$_W$.

<table>
<thead>
<tr>
<th>Calculated value</th>
<th>OMD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual OMD</td>
<td>$36 \pm 1.1^a$</td>
</tr>
<tr>
<td>Predicted OMD$_M$</td>
<td>$42 \pm 0.6^b$</td>
</tr>
<tr>
<td>Predicted OMD$_W$</td>
<td>$51 \pm 0.2^c$</td>
</tr>
</tbody>
</table>

$^{abc}$ values in the same column with a different superscript are significantly different ($p < 0.001$)

Table 9.6. Average ($\pm$ SE) ME and predicted MEM.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ME (MJ/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual ME</td>
<td>$3.7 \pm 0.2^a$</td>
</tr>
<tr>
<td>Predicted MEM</td>
<td>$6.0 \pm 0.1^b$</td>
</tr>
</tbody>
</table>

$^{ab}$ values in the same column with a different superscript are significantly different ($p < 0.001$)

The actual and predicted OMD and ME of each of the four diets were compared and are shown in Figures 9.1 and 9.2, respectively. The average OMD of Diet 1 and 3 was greater ($p < 0.001$) than Diets 2 and 4. No relationship was found between the OMD of the consumed diet and the predicted OMD$_M$ ($p > 0.05$) and OMD$_W$ ($p > 0.05$). However, the higher nutritive value of Diets 1 and 3 was reflected in the predicted OMD$_W$ values, although the equation failed to identify the degree of variation between the diets.

In terms of ME, Diet 1 and Diet 3 were similar ($p > 0.05$) and greater than Diets 2 and 4 ($p < 0.001$) and diet 4 had a higher ME value than Diet 2 ($p < 0.001$) but no relationship ($p > 0.05$) was found between the consumed diet ME and the predicted MEM.
Figure 9.1. Average (± SE) OMD and predicted OMD$_M$ and OMD$_W$ for the four diets. Actual diet OMD (blue); predicted OMD$_M$ (red); predicted OMD$_W$ (green). The actual and predicted values for each diet were significant different (p < 0.001), with the exception of the actual OMD and OMD$_M$ value of Diet 3.

9.3.4 NIRS calibrations
The calibration and validation statistics developed using NIRS for DMD, OMD, ME, CP intake (CPI) and CP digestibility (CPD) are shown in Table 9.7. The average standard error of laboratory method (SEL) was 0.5. All of the calibration equations recorded $R^2$ values of less than 0.80. An exception to this was CPI that recorded the highest calibration $R^2$ value (0.88) as well as the highest SEC and SECV values and the lowest validation $R^2$ value and RPD ratio (0.24 and 0.11, respectively).
The DMD calibration and validation recorded the highest $R^2$ values of 0.77 and 0.61, respectively. The SEC and SECV of DMD were similar (0.026 and 0.036, respectively) and the RPD ratio was greater than 3. The OMD calibration similarly recorded an RPD ratio greater than 3 and $R^2$ calibration and validation values of 0.78 and 0.29, respectively and an SECV close to twice the value of the calibration SEC.

From the array of calibration equations based on the highest $R^2$, lowest SEC/SECV, highest RPD and bias closest to zero, the ‘best’ equation for each component was selected. The calibration equations were then used to predict the parameters of eight test samples. Table 9.8 details the respective averages, standard errors and standard errors of prediction (SEP).

The difference between the references and predicted values of each of component was not significant ($p > 0.05$). The lowest SEP values were recorded for ME, OMD and DMD (0.35, 0.8 and 1.08, respectively).
Table 9.7. Calibration and validation statistics for fNIRS of sheep diets.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Spectral pre-processing</th>
<th>Calibration</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R²</td>
<td>SEC</td>
</tr>
<tr>
<td>DMD</td>
<td>First derivative (FD)</td>
<td>0.77</td>
<td>0.026</td>
</tr>
<tr>
<td>OMD</td>
<td>FD</td>
<td>0.78</td>
<td>0.024</td>
</tr>
<tr>
<td>ME</td>
<td>Straight line subtraction</td>
<td>0.55</td>
<td>0.62</td>
</tr>
<tr>
<td>CPI</td>
<td>FD + vector normalisation</td>
<td>0.88</td>
<td>3.84</td>
</tr>
<tr>
<td>CPD</td>
<td>Min – Max normalisation</td>
<td>0.35</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Table 9.8. Determined reference values (using established chemical analyses and calculations) and predicted chemical and nutritive values (using developed fNIRS predictive equations)

<table>
<thead>
<tr>
<th></th>
<th>n= 8</th>
<th>Reference</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SE</td>
<td>SE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMD (%)</td>
<td>32.57</td>
<td>2.02</td>
<td>31.48</td>
</tr>
<tr>
<td>OMD (%)</td>
<td>36.55</td>
<td>1.70</td>
<td>35.75</td>
</tr>
<tr>
<td>ME (MJ/kg DM)</td>
<td>3.74</td>
<td>0.40</td>
<td>3.39</td>
</tr>
<tr>
<td>CPI (g/d)</td>
<td>50.11</td>
<td>4.34</td>
<td>51.25</td>
</tr>
<tr>
<td>CPD (%)</td>
<td>24.46</td>
<td>3.03</td>
<td>27.60</td>
</tr>
</tbody>
</table>

9.4 Discussion

9.4.1 Diet quality, chemical composition and digestibility

The *in vivo* digestibility and ME of the four diets were very low with all DOMD values less than 40% (range 28 – 38) and a maximum of 4.6 MJ ME/kg DM (range 2.6 – 4.6). In comparison, unsorted average pasture cuts harvested (in May, August and December) at the site had an average *in vitro* DOMD of 50% (range 46 - 53) and ME content of 7.2 MJ/kg DM (range 6.3 – 7.6 MJ/kg DM). Although lower DOMD and ME values were recorded in the studied diets a greater range of DOMD and ME values were obtained in comparison to the unsorted pasture cuts from the site. The NDF and ash content of the four diets was similar to the average pasture cuts (705 vs. 695 g/kg DM for NDF and 79 vs. 85 g/kg DM for ash, respectively). However, the CP and ADF contents of the four diets were substantially lower in comparison to average pasture cuts (80 vs. 118 g CP/kg DM and 147 vs. 390 g ADF/kg DM, respectively). The lower nutritive value in terms of DOMD, ME and CP of the four study diets in comparison to the average pasture cuts may in part be a result of the processes involved in the harvesting, drying and storing of the forage that can result in substantial losses of forage DM and nutrients (Rotz and Muck 1994). The low CP content of the diets may be attributed to the low fertility of the soil (that had no fertiliser applied) and the negligible quantities of
legumes within the harvested pasture. The lower than expected DOMD and ME values may in part be a result of the time required to harvest and then store sufficient material for each feeding study that meant samples may have respired substantially post-harvest and as a consequence some of the most digestible nutrients would have been removed (Rotz and Muck 1994). Furthermore, the pre-feeding treatment of drying (at 60°C for 48 h) and storing the pasture (at room temperature prior to the feeding trial) may have reduced the nutritive value of the pasture. Beever et al. (1976) investigated the effect of three dehydration treatments (145°C inlet temperature, 900°C inlet temperature and 100°C oven drying for 18 h) and freezing on pasture quality and digestion. They found heating treatments decreased N solubility and energy digestibility but slightly increased cellulose content. Similarly, Graham (1964) found that drying (at 80°C in oven) *Paspalum* spp. and white clover pasture reduced the digestibility of OM and the digestible energy and protein of the forage. Alomar et al. (1999) found that when silage was oven dried (at 105°C for 48 h) CP content and DOMD decreased, resulting in increases of crude fibre, NDF and ADF contents. The lower DOMD, ME and CP content and similar NDF and ash content of the study diets in comparison to the average pasture cuts support these findings. However, the very low ADF value of the study diets is contrary to the observations of Alomar et al. (1999) and Beever et al. (1976) and furthermore the average ADF value of the diets does not reflect the low digestibility of the diets.

The nutritive value (of the diet) was highest in summer and late autumn (Diet 1 and 3, respectively) and lowest in early autumn (March 2011). Seasonal variation in the nutritive value of the diet is expected and depending upon botanical composition and climatic conditions and pasture quality is typically lowest in winter for the pasture species observed in the study. However, the mechanical harvesting and subsequent regrowth of the pasture in this study limit comparisons of the seasonal effects on grazed pastures.

The low DM intake of the animals within the study reflects the low nutritive value of the four diets that would be insufficient to support maintenance of the animals. Similarly, the nutritive value of the average pasture cuts may support maintenance, but not production and/or reproduction of grazing animals.
9.4.2 Development of faecal indices predictive equations

No accurate predictive model of diet quality from faecal indices was able to be derived from the dataset. The lack of an accurate predictive model is similar to the experience of Leite and Stuth (1990), who found no individual faecal parameter was highly correlated with diet quality and were unable to accurately predict the diet quality of grazing cattle (n = 287) from f/N fractions and condensed tannins. The authors concluded derived multiple regression equations to predict dietary CP (R² = 0.57) and CP intake (R² = 0.51) were of limited value due to the low correlation coefficients. The poor correlation between diet and faecal parameters in the study was likely to be a result of the presence of dietary tannins, identified later by Wehausen (1995).

The significant models obtained in this study from multiple regression models that predicted dietary attributes from faecal indices on a DM basis were ADF (R² = 0.44), OM (R² = 0.30) and DMD (R² = 0.15). However, the very low R² values similarly would indicate these models are of limited use. It is unlikely that tannins were present in the studied pastures and in contrast to this study Leite and Stuth (1990) successfully found a strong relationship between f/N output and OM intake (R² = 0.84). Faecal indices have been used effectively to predict diet digestibility, quality and intake in sheep (Wehausen 1995; Boval et al. 2003; Wang et al. 2009), cattle (Holloway et al. 1981; Holechek et al. 1982a; Wehausen 1995; Lukas et al. 2005) and deer (Mubanga et al. 1985; Hodgman et al. 1996; Kamler and Homolka 2005). Holloway et al. (1981) identified associations between f/N and DMD (R² = 0.67) and f/N and digestible DM intake (R² = 0.66) in cattle (n = 39) consuming grass and legumes and Holechek et al. (1982a) found strong correlations between f/N and diet N (R² = 0.83) in cattle (n = 40) grazing mountainous pasture. They also found f/N and faecal sample in vitro digestibility using a multiple regression equation accurately predicted diet in vitro digestibility (R² = 0.83). Similarly, Nunez-Hernaznez et al. (1992) using multiple regression equations established robust relationships between total faecal output, f/N output and f/N with N intake in cattle (n = 32; R² = 0.91) and goats (n = 48; R² = 0.97) consuming diets of forbs, shrubs and lucerne hay. In the same way Lukas et al. (2005) identified a relationship between f/CP and diet OMD (R² = 0.82) in cattle (n = 445) and in sheep (n = 40) and goats (n = 40) consuming a tropical pasture. Boval et al. (2003) found f/CP reliably predicted diet OMD (R² = 0.74). Wang et al. (2009) found f/CP predicted diet OMD in sheep (n = 721) fed a variety of forage types and Mahipala et al. (2009) using multiple regression equations correlated faecal indices (f/NDF, f/ADL, f/Ash and f/N) with
diet OMD ($R^2 = 0.78$) and ME ($R^2 = 0.78$) in sheep ($n = 174$) consuming oaten hay and browse species.

The poor correlation between faecal and diet parameters in this study in comparison to the aforementioned studies do not invalidate these studies, but rather highlights the limitations of this study. It is likely the small sample size ($n = 24$) and overall narrow range of values, were insufficient. Furthermore, the development of a reliable predictive model may have been limited by the small number of diets ($n = 4$) and narrow range of forage nutritive value used in this study in comparison to other studies (Holechek et al. 1982a; Lukas et al. 2005; Wang et al. 2009; Mahipala et al. 2009).

The common thread of the prediction of diet quality from faecal indices reported in the previous studies was that trends in faecal composition were associated with and confounded by diet quality factors and predictive equations were specific to each situation in terms of pasture composition, presence of tannins, season and animal species. Two exceptions to this were the potentially ‘generic’ equations developed by Mahipala et al. and Wang et al. and the applicability of these equations was evaluated.

### 9.4.3 Evaluation of faecal chemistry predictive equations

The predicted $\text{OMD}_M$ and $\text{OMD}_W$ of the four diets were significantly different ($p < 0.001$) to the actual OMD of the diets consumed by the animals. No significant relationship ($p > 0.05$) was identified between the predicted $\text{OMD}_M$ and $\text{OMD}_W$ and the OMD of the diets actually consumed by the animals; although the predicted $\text{OMD}_W$ values of the diets reflected a similar trend to the actual OMD of the consumed diets.

The predicted $\text{ME}_M$ value and the actual ME of the consumed diet were significantly different ($p < 0.001$) and as found with the predicted $\text{OMD}_M$ data no relationship ($p > 0.05$) was identified between the predicted and observed ME values of animal’s diet.

The discrepancies between the observed and predicted OMD and ME content of the diets are likely to be a consequence of the low quality (DMD and ME) of the pasture being outside of the range of pasture quality of the feeding studies from which the predictive equations were derived. This was reflected by the predicted $\text{OMD}_W$ values being greater than the actual OMD of the diets consumed by the animals in comparison to the equations consistently under estimating diet OMD in the derived pastures. The comparatively low quality of the pasture in this study is likely to have limited the accuracy of the equations in comparison to the predicted values reported in Chapters 5.
and 7. The average (± SE) DOMD and ME values (from *in vitro* analyses) reported in Chapter 5 were significantly higher (p < 0.001) than the same parameters measured (via *in vivo* analyses) in this study; the average DOMD for the pasture harvested in Chapter 5 and this chapter, respectively was 56 (± 2.4) vs. 34 (± 2.4) % whilst the ME was 8.2 (± 0.5) vs. 3.8 (± 0.5) MJ/ kg DM. The results of this chapter suggest that the equations potentially under estimated diet OMD in animals grazing fresh native pastures (Chapters 5 and 7). However, the differences in the quality of the dried pasture in this study and the fresh pasture from the previous studies indicate it is likely the predictive equations were more applicable to fresh rather than dried pasture and the predicted values may have been closer to the actual values of the consumed pasture. Of the two published ‘generic’ predictive equations the values predicted by the Wang *et al.* (2009) equation reflected a similar trend to the OMD of the diets consumed by the animals and in part support the findings of Chapter 5, that predicted OMD$_W$ values could be used to compare the diet quality of animals, as applied in Chapter 7. The results of the predicted ME$_M$ values also support the results of Chapter 5 and 7 that highlight the limitations of the equation within the studied pasture. Whilst not providing accurate values, the calculated values of OMD$_W$ do provide a means of comparative analysis and identifying trends in diet quality over time and between animals. However, neither equation accurately predicted the absolute values of the quality parameters of the diet and the limited dataset failed to enable development of an appropriate predictive model of diet quality. As a consequence, the need for a non-invasive method of determining the diet quality of grazing animals within these complex native pastures cannot be overstated. Whilst the development of an accurate predictive model is both costly and time consuming, it is fundamental to researchers and producers in the enhancement of animal and pasture production and positive natural resource outcomes within heterogeneous landscapes. Thus, future feeding studies of native pastures from the studied region are recommended and the collaboration of researchers domestically and internationally is essential to the future development of a truly accurate and applicable ‘generic’ equation to predict the diet quality of animals grazing within the studied native pasture. In the meanwhile an alternative method can be the use of f/NIRS.

### 9.4.4 Development of f/NIRS predictive equations

The low SEL value (0.5) found here indicates the procedures used in sample preparation were within an acceptable range (Hruschka 1987) and introduced little error. The
developed f/NIRS calibrations compared favourably with acceptable and developed calibrations within the relevant literature (Table 9.9)

For DMD the developed f/NIRS calibration statistics ($R^2 = 0.77$, $SEC = 0.026$ and $SECV = 0.036$) compared favourably with DMD statistics recorded by Garnsworthy and Unal (2004) in cattle but were less than those derived by Kumara Mahipala et al. (2010). The $R^2$ value associated with DMD in this study was slightly less than the acceptable value of 0.8 (Williams 2004). However, in comparison to the reference values the developed calibration performed well and recorded an SEP value of 1.08 and the developed DMD f/NIRS predictive equation is considered to be adequate and warrants further investigation.

The $R^2$ value (0.78) for the f/NIRS predictive equation for OMD was similarly just lower than the acceptable value and similar to $R^2$ values (for OM) derived by Li et al. (2007b) and OMD values of Fanchone et al. (2007) and Decruyenaere et al. (2009) in sheep and higher than that observed by Landau et al. (2004) in goats and lower than the $R^2$ values derived by Decandia et al. (2009) and Kumara Mahipala et al. (2010) in sheep. Lyons and Stuth (1992) and Boval et al. (2004) similarly, observed higher $R^2$ values for f/NIRS predictive equations for OMD in cattle, while Leite and Stuth (1995) recorded a higher value for OMD in goats. The SEC of the OMD f/NIRS calibration (0.024) was similar to Boval et al. and Decruyenaere et al. and lower than values recorded by Lyons and Stuth, Leite and Stuth, Li et al., Decandia et al. and Kumara Mahipala et al. Whilst the $R^2$ value of cross validation (0.29) was very low for the derived equations in this study the SECV and SEP were also low (0.045 and 0.8, respectively) and the RPD was greater than 3. As a consequence the f/NIRS predictive equation for OMD may provide a method of comparison between diets and further investigation of the applicability of the equation is recommended.

Robust calibration statistics have been developed for other diet parameters (CP, CPI and ME) using f/NIRS. Lyons and Stuth (1992) developed a robust calibration for diet CP of cattle, Kidane et al. (2008) predicted diet CP in donkeys and Glasser et al. (2008) similarly predicted diet CP of goats. Crude protein intake has been predicted from f/NIRS in sheep by Decandia et al. (2009) and Fanchone et al. (2007) and Kumara Mahipala et al. (2010) estimated diet ME of sheep. In contrast to these studies the derived calibration statistics for ME, CPI and CPD in this study were considered to be unacceptable as predictive equations based upon the calibration $R^2$ values ($ME = 0.55,$
CPD = 0.35), validation $R^2$ values (ME = 0.32, CPI = 0.24, CPD = 0.59) as well as SEC (CPI), SECV (CPI) an SEP (CPI, CPD) values. Similarly, Kumara Mahipala et al. (2010) were unable to accurately predict CP or CPD.

The development of robust f/NIRS calibrations from the studied diets may have been inhibited by the small number of diets and that they were of low digestibility. Coleman and Murray (1993) found faecal spectrum was negatively correlated with digestibility and likely the result of greater accumulation of fibre resides in the faeces at low digestibility (Decruyenaere et al. 2009).

The reasonable predictive ability of the DMD and OMD and to a lesser extent ME calibration equations derived from this study are of interest and suggest the indirect prediction of the diet quality of grazing animals via f/NIRS equations is possible and thus warrant further investigation in grazing animals.

Table 9.9. Summary of acceptable and developed f/NIRS calibration statistics by analyte and species.

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Species</th>
<th>Calibration statistics</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMD</td>
<td>Cattle</td>
<td>$R^2$ = 0.68, SEC = 0.03, SECV = 0.03</td>
<td>Garnsworthy and Unal (2004)</td>
</tr>
<tr>
<td></td>
<td>Sheep</td>
<td>$R^2$ = 0.83, SEC = 21.6, SECV = 24.3</td>
<td>Kumara Mahipala et al. (2010)</td>
</tr>
<tr>
<td>OM</td>
<td>Sheep</td>
<td>$R^2$ = 0.78-0.80, SEC = 1.51-1.58, SECV = 1.65-2.60</td>
<td>Li et al. (2007b)</td>
</tr>
<tr>
<td>OMD</td>
<td>Cattle</td>
<td>$R^2$ = 0.80, SEC = 1.66, SECV = 1.65</td>
<td>Lyons and Stuth (1992)</td>
</tr>
<tr>
<td></td>
<td>Cattle</td>
<td>$R^2$ = 0.72, SEC = 0.02, SECV = 0.02</td>
<td>Boval et al. (2004)</td>
</tr>
<tr>
<td></td>
<td>Goats</td>
<td>$R^2$ = 0.93, SEC = 2.02, SECV = 2.12</td>
<td>Leite and Stuth (1995)</td>
</tr>
<tr>
<td></td>
<td>Sheep</td>
<td>$R^2$ = 0.81, SEC = 1.78, SECV = 2.02</td>
<td>Fanchone et al. (2007)</td>
</tr>
<tr>
<td></td>
<td>Sheep</td>
<td>$R^2$ = 0.85, SEC = 21.6, SECV = 2.50</td>
<td>Kumara Mahipala et al. (2010)</td>
</tr>
<tr>
<td></td>
<td>Sheep</td>
<td>$R^2$ = 0.76, SEC = 0.03, SECV = -</td>
<td>Decruyenaere et al. (2009)</td>
</tr>
<tr>
<td></td>
<td>Goats</td>
<td>$R^2$ = 0.72, SEC = 10.5, SECV = 12.3</td>
<td>Landau et al. (2004)</td>
</tr>
<tr>
<td></td>
<td>Sheep</td>
<td>$R^2$ = 0.90, SEC = 2.55, SECV = 3.44</td>
<td>Decandia et al. (2009)</td>
</tr>
<tr>
<td>CP</td>
<td>Cattle</td>
<td>$R^2$ = 0.92, SEC = 0.89, SECV = 0.86</td>
<td>Lyons and Stuth (1992)</td>
</tr>
<tr>
<td></td>
<td>Donkey</td>
<td>$R^2$ = 0.97, SEC = 0.77, SECV = 1.19</td>
<td>Kidane et al. (2008)</td>
</tr>
<tr>
<td></td>
<td>Goats</td>
<td>$R^2$ = 0.93, SEC = 0.62, SECV = 0.87</td>
<td>Glasser et al. (2008)</td>
</tr>
<tr>
<td>CPI</td>
<td>Sheep</td>
<td>$R^2$ = 0.93, SEC = 36.52, SECV = 55.86</td>
<td>Decandia et al. (2009)</td>
</tr>
<tr>
<td></td>
<td>Sheep</td>
<td>$R^2$ = 0.99, SEC = 0.15, SECV = 0.23</td>
<td>Fanchone et al. (2007)</td>
</tr>
<tr>
<td>ME</td>
<td>Sheep</td>
<td>$R^2$ = 0.95, SEC = 0.24, SECV = 0.30</td>
<td>Kumara Mahipala et al. (2010)</td>
</tr>
</tbody>
</table>


9.5 Conclusion

Equations to predict diet quality (based on chemical analysis of faeces) could not be developed using the data generated from the animal house study. Furthermore, the OMD and ME of the diets could not be predicted from equations developed by Wang et al. (2009) and Mahipala et al. (2009).

Equations to predict diet quality (DMD, OMD and perhaps ME) could be developed from fNIRS. Further development of fNIRS calibration equations has great potential as a quantitative method of examining the diet quality of sheep grazing within the studied native pastures. Given this success, this information can be used to reassess the quality of the diets reported in previous chapters.
Chapter 10. Analysis of Previously Reported Diet Quality Using fNIRS

10.1 Introduction
The estimation of diet quality by grazing animals (as noted in Chapters 5 and 7) was fraught with difficulties. The most promising technique for making these estimates proved to be fNIRS, where controlled studies demonstrated workable relationships for DMD, OMD and ME (Chapter 9). In this chapter the applicability of the derived fNIRS predictive equations to the studied pasture was evaluated and compared with the values estimated from faecal chemistry predictive equations (Mahipala et al. 2009; Wang et al. 2009) and the decision support tool GrazFeed® (Freer et al. 2010). The calibration was applied to faecal samples of ewes grazing within contrasting grazing systems in different physiological states (reported in Chapter 7). The first experiment was when ewes were lactating with lambs at foot, in late spring and the second involved dry, non-pregnant ewes, in late summer.

10.2 Materials and methods

10.2.1 Experimental design
The experiment was conducted at the EverGraze Central Tablelands Proof Site over two time periods. The first was when ewes were with lambs and lactating at the end of spring (18th November to 8th December 2010), whilst the second period occurred following weaning when ewes were dry and not pregnant in early autumn (2nd to 22nd March 2011). The experiment involved ewes managed within a CG treatment and a 20-paddock RG treatment.

Refer to Chapter 7 sections 7.2.1 to 7.2.5 and 7.2.9 to 7.2.11 for details of the experimental design, climatic data, animals, pasture assessment as well as plant and faecal sampling.

10.2.2 Faecal collection and analysis
Three fresh (composite) faecal samples were collected from pasture at the same time each day from each treatment (0900 h from the RG treatment and 1000 h from the CG treatment). Each composite sample comprised five faecal samples (presumably representing five sheep). Samples were collected from both treatments for the duration of the grazing of the RG paddock and four subsequent days after the completion of
grazing to account for the rate of passage of digesta. Faecal collection methods and analysis are described in Chapter 3 sections 3.2.2.1 and 3.5.2.

At the time of chemical analysis, NIR spectra of the faecal samples were obtained on a Brucker® MPA NIR spectrometer (Bruker Optik GmbH, Ettlingen, Germany) with a spectral range of 3600 µm to 12500 µm. Prior to scanning, the dried and ground faecal samples were placed in a desiccator for 1 h to equilibrate with ambient temperature. Faecal NIRS spectra were used to predict the diet DMD, OMD and ME using /NIRS equations developed in the previous chapter (Chapter 9).

The faecal chemistry predictive equation of Mahipala et al. (2009) estimated diet MEM and the equation of Wang et al. (2009) estimated OMDW. The equations were as follows;

\[
\text{Diet MEM (MJ/kg DM)} = 12.32323 - 8.25181 \left( \frac{f \text{ADL}}{f \text{NDF}} \right) - 0.01522 (f \text{Ash}) - 0.07933 (f \text{N})
\]

\[
\text{OMD}_W = 0.899 - 0.644 \times \exp \left( -0.5774 \times \text{faecal CP (g/kg OM)} / 100 \right).
\]

10.2.3 Statistical analyses
The average predicted diet quality of the ewes within the contrasting grazing systems from f/NIRS were analysed using ANOVA (Genstat® 13th edn, Hemel Hempstead United Kingdom) and differences were significant when \( p < 0.05 \).

10.3 Results
10.3.1 Analysis of previous faecal samples using f/NIRS prediction equations
The developed f/NIRS calibrations (to predict dietary DMD, OMD and ME) were applied to the faecal samples from lactating ewes grazing with lambs at foot (November - December 2010) and dry, non pregnant ewes (March 2011) and the results are presented in Figure 10.1 and Figure 10.2, respectively.

The quality of the diet of lactating ewes with lambs within the contrasting grazing systems in late spring was similar on day 1, 3 and 6 and diet quality of the CG ewes was higher than RG ewes on day 2, 4 and 5 for the three estimated parameters. The average DMD of the diet of CG ewes was greater (\( p < 0.001 \)) than RG, although the values were higher than is theoretical possible (113 % vs. 106 %, respectively). In the same way, the OMD and ME of the diet of CG ewes was higher (\( p < 0.05 \)) than RG ewes (88 % vs. 83
and (14.1 vs. 12.9 MJ/kg DM), respectively. The estimated daily ME intake for CG and RG lactating ewes was 19.6 and 16.9 MJ/d, respectively based upon the predicted GrazFeed® DM intake reported in Chapter 7, section 7.3.1.3 (of 1.39 kg/hd/d for CG ewes and 1.30 kg/hd/d RG).

The trends in DMD, OMD and ME over time were similar in dry ewes in March 2011. The DMD, OMD and ME of the diet of CG ewes was higher on day 1, similar on days 2 - 5 and lower on day 6 than RG ewes. The average DMD, OMD and ME of the diet of CG ewes (65 %, 50 % and 6.4 MJ/kg DM, respectively) was higher than RG ewes (61 %, 49 % and 6.2 MJ/kg DM, respectively). However, the difference between the two grazing systems was not significant (p > 0.05). The estimated daily ME intake of CG was calculated as 6.7 MJ/d for CG ewes and 6.4 MJ/d for RG ewes using the DM intake predicted by GrazFeed® (reported in Chapter 7, section 7.3.2.3) of 1.05 and 1.04 kg/hd/d for CG and RG ewes, respectively.
Figure 10.1. Average (± SE) DMD, OMD and ME (from f/NIRS predictive equations) of the diet consumed by lactating ewes (with lambs) grazing within differing grazing systems over six days in late spring. CG (green); RG (blue)
Figure 10.2. Average (± SE) DMD, OMD and ME (from f/NIRS predictive equations) of the diet consumed by dry and not pregnant ewes grazing within differing grazing systems over six days in late summer. CG (green); RG (blue)
10.3.2 Comparison of diet quality estimates

The average estimated diet quality values derived from f/NIRS, GrazFeed® and faecal chemistry predictive equations of lactating ewes with lambs and dry, non pregnant ewes are shown in Table 10.1 and Table 10.2, respectively.

All of the diet quality parameters estimated by the various methods were substantially different for lactating ewes with lambs. The estimated diet DMD from f/NIRS and GrazFeed® were considerably different; however, it should be noted the magnitude of difference between the grazing systems was similar for the two methods. In the same way the estimated OMD values between the methods were different although the trend of a higher OMD in CG ewes was common between f/NIRS and OMD_W estimates. Using f/NIRS and GrazFeed®, ME intake was higher in CG ewes in comparison to RG ewes; in contrast predicted ME_M reported a 4% higher diet ME intake in RG ewes, which is unlikely to be significant. The overall trend is for higher quality diet intakes of CG than RG ewes.

<table>
<thead>
<tr>
<th></th>
<th>DMD (%)</th>
<th>OMD (%)</th>
<th>ME intake (MJ/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f/NIRS</td>
<td>GrazFeed</td>
<td>f/NIRS</td>
</tr>
<tr>
<td>CG</td>
<td>113</td>
<td>62</td>
<td>88</td>
</tr>
<tr>
<td>RG</td>
<td>106</td>
<td>62</td>
<td>83</td>
</tr>
</tbody>
</table>

Table 10.2. Average estimated DMD, OMD and ME of the diet of dry and not pregnant ewes grazing within differing grazing systems in late summer.

<table>
<thead>
<tr>
<th></th>
<th>DMD (%)</th>
<th>OMD (%)</th>
<th>ME intake (MJ/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f/NIRS</td>
<td>GrazFeed</td>
<td>f/NIRS</td>
</tr>
<tr>
<td>CG</td>
<td>65</td>
<td>58</td>
<td>50</td>
</tr>
<tr>
<td>RG</td>
<td>61</td>
<td>58</td>
<td>49</td>
</tr>
</tbody>
</table>

The estimated dietary DMD and OMD from f/NIRS and GrazFeed® and f/NIRS and OMD_W, respectively were similar for dry and not pregnant ewes and reflected the same trend of higher OMD in CG ewes. The ME intake predicted from f/NIRS and ME_M were lower than the values estimated from GrazFeed®. Both f/NIRS and GrazFeed® estimated a higher ME intake of CG ewes than RG ewes, whereas ME_M values estimated the converse, a 9.5% higher ME intake in RG ewes. This pattern is similar to that found with lactating ewes.
10.4 Discussion

The estimated diet quality parameters of DMD, OMD and ME intake from f/NIRS predictive equations for dry, non pregnant ewes followed similar trends over time and reflected the expected association between the digestibility and ME content of an animal’s diet (Court *et al.* 2010), the values for lactating ewes with lambs were considerably different. The estimated value of the DMD of the diet of lactating ewes with lambs of 113% and 106% as well as the OMD values (88% and 83%) and ME intake of 19.6 and 16.9 MJ/d are not sensible and do not reflect the quality of the pasture. The average green pasture at the time was estimated (from wet chemistry analyses) as 8 MJ/kg DM and 8.7 MJ/ kg DM for the RG and CG system, respectively. Furthermore, the highest ME values of plant species was recorded in *Trifolium subterraneum* of 9.5 and 10 MJ/kg DM for the RG and CG system, respectively. These values are likely to be a result of the pasture in late spring being of substantially higher quality and outside of the low range of pasture quality of the feeding studies from which the predictive equations were derived. The lactation of the ewes together with the higher dietary requirements and intake of the animals may have contributed to the unrealistic values. The predicted ME\(_M\) values estimated a higher diet quality of RG ewes that does not support the predicted digestibility of the pasture or the animal’s production. The values estimated by f/NIRS for lactating ewes with lambs support the previous findings of a higher diet quality and animal production (ewe and lamb live weight) of CG animals (Chapter 7).

The estimated diet quality parameters of the dry, non pregnant ewes from the second experiment were reasonable for the pasture quality at the time and comparable to the predicted values from GrazFeed\(^*\) of DMD. Both f/NIRS predicted DMD and ME intake values reflected the same trend as the GrazFeed\(^*\) values of a higher diet quality of CG ewes in comparison to RG ewes. Similar, to the first experiment the predicted ME\(_M\) values estimated a higher diet quality of RG ewes that does not reflect the predicted pasture digestibility or animal production. The ME\(_M\) predictive equation derived by Mahipala *et al.* (2009) was based on the feeding of tannin containing browse-species. As a result of the discrepancies between the predicted values and animal production in this chapter and previous chapters (Chapter 5 and 7) it is concluded the ME\(_M\) predictive equations are considered to be inaccurate and unsuitable for use within the studied pasture. The estimated higher diet quality of CG ewes from f/NIRS analysis of dry and
not pregnant ewes support the previous findings of a higher diet quality and animal production (ewe and lamb live weight) of CG animals (Chapter 7).

The reasonable association between the diet parameters predicted from f/NIRS and GrazFeed® for dry, non pregnant ewes is unexpected due to the limited range of pasture quality, diets (n = 4) and sample numbers (n = 24) from which the predictive f/NIRS equations were derived. The lower digestibility of the pasture during late summer in comparison to late spring is likely to in part explain the similar DMD and ME values. The lower estimated ME values from f/NIRS may be a result of the pre-feeding treatment of drying (Graham 1964; Beever et al. 1976) and the time required to harvest sufficient material for the animal house experiment that meant samples may have respired significant amounts of the more volatile material before drying (Rotz and Motz 1994).

Determining the diet quality of grazing animals is inherently difficult and many producers and researchers rely on direct chemical analysis of plant material to assess forage quality and infer animal nutritional status. The diet quality values of DMD, OMD and ME intake predicted from f/NIRS followed the same trend as the GrazFeed® values. The values estimated from the Wang et al. (2009) equation followed a similar trend to the predicted OMD of the diet. As a result f/NIRS and to a lesser degree the Wang et al. (2009) equation offer a means of qualitative analysis of trends in diet quality of grazing sheep over time provided appropriate, accurate and effective calibration equations are available or developed (Lyons and Stuth 1992). Thus the further development of an accurate quantitative means of determining the diet quality of animals is recommended. To this effect, it is essential further feeding studies are conducted with the studied native pasture and a wider range of pasture qualities together with the feeding of fresh rather than dried forage.

These results suggest that the indirect prediction and qualitative analysis of the diet quality of grazing animals from f/NIRS analysis is possible, but they should only be used within the range of the original study used to develop the equations. The development of a calibration database for either faecal chemistry indices or f/NIRS predictive calibrations involves substantial and often limiting costs. A major benefit of NIRS analysis in comparison to chemical analysis is the cost-effective, rapid analysis without the need of reagents or potential safety hazards (Mark et al. 2002). Where the
investment and development of a database is possible it is proposed that the
development of an f/NIRS calibration database should be a priority.

10.5 Conclusion
The developed f/NIRS predictive calibrations reflected the animal’s diet quality over
time as estimated from GrazFeed® and the OMD predictive equation developed by
Wang et al. (2009). The results support the findings of Chapter 7 that CG ewes in
different physiological states consumed a diet of higher quality in terms of DMD, OMD
and ME than RG ewes that was reflected in higher live weight and BCS of ewes and
greater growth rates of lambs.

The results indicate the indirect prediction and qualitative analysis of the diet quality of
grazing animals from f/NIRS analysis and faecal chemistry predictive equations is
possible. However, further development of a larger calibration database that
incorporates a wider variety of pasture qualities and fresh forage is essential to the
development of an accurate quantitative method of predicting the diet quality of grazing
animals.
Chapter 11. General Discussion

Livestock production depends primarily on the quantity and quality of the diet selected by those animals. Within complex, mixed species natural pastures the decisions made by livestock about what to graze are poorly understood. In this study the use of non-invasive techniques including intensive pasture monitoring, faecal indices and GPS monitoring together with traditional methods of measuring sheep live weight, BCS, wool production and the nutritive value of plants has expanded current knowledge of the nutrition and diet selection of sheep grazing native pastures in the Central Tablelands of NSW. Grazing behaviour by livestock has consequences for the longer-term management and sustainability of grassland resources.

11.1 Research questions

11.1.1 How do different grazing systems affect live weight, body condition score and wool production of sheep?

Currently, knowledge of the effect of flexible, high-intensity grazing systems on sheep production in native pastures in the high rainfall zone of southern Australia is based on a limited number of studies (e.g. Dowling et al. 2006) and inferred from studies involving low-intensity, fixed grazing systems in native pastures (Lodge et al. 2003a; 2003c) and improved pastures (Morley et al. 1969; Lloyd-Davies and Southey 2001; Waller et al. 2001; Warn et al. 2002; Chapman et al. 2003). The results of the previous research are highly variable and are complicated by a plethora of confounding factors including; variability of management practices, landscapes and grazing environments, climatic conditions, study duration, study methodologies and whether treatments were replicated.

The analyses in Chapter 4 provided information on the effect of grazing management systems on the live weight and BCS of ewes and lambs and the wool production of ewes from 2008 to 2011. Ewes managed within a CG system consistently out performed RG ewes in terms of live weight, BCS and the live weight and growth of CG lambs was greater than animals managed within the RG system. Lamb birth weight was similar between management systems and wool growth and production of ewes was comparable between systems. However, differences in wool production and growth were recorded between production years.
The significant variation in live weight, BCS and wool production of ewes between years was associated with differences in climatic conditions, in particular annual rainfall and the resulting FOO (Freudenberger et al. 1999).

The greater live weight and BCS of CG animals may in part be explained by the lower SR of the system. The SR of the RG animals within this study (23 – 33% higher) was substantially greater than the elevated carrying capacity of RG animals by Warn et al. (2002) in a district with similar levels of pasture productivity who increased the SR of RG by up to 17 - 21% under high and low P fertiliser, respectively without compromising animal performance. The influence of grazing systems and SR (rather than a simple SR effect) was apparent when the greatest differences in ewe live weight (5.5 kg/hd) and BCS (0.5) between systems was recorded when the SR of the RG system was ≈ 25% higher and the animals were managed within the contrasting systems the entire year.

It should be noted the higher SR of animals (with a lower live weight) in a RG system is associated with greater live weight/ha in comparison to a CG system and higher live weight/ha is considered to be a primary determinant of profitability, though this depends upon the position on the response curve (Kemp and Michalk 2007). However, comparisons on a per ha basis need to also consider the cost of infrastructure and labour associated with the implementation and management of a RG system that were not able to be considered on a commercial scale within this study. As a result, this study focused upon individual animal live weight, BCS and lamb growth to compare contrasting grazing systems and gaining a greater understanding of how grazing systems function.

The smaller differences in lamb live weight in December 2008 and ewe live weight in April and May of 2009 and 2010 in this study indicate a benefit of a RG system may be increased FOO as a result of forage being held over from the management of animals’ grazing location. The results suggest RG may prove advantageous when rainfall is below average and through summer and autumn.

The greater live weight and BCS of individual CG ewes will have contributed to the higher growth rate of CG lambs (Behrendt et al. 2011; Thompson et al. 2011a). The greater production of the CG animals may be attributed to the lower SR of the system together with differences in pasture quality between the systems and the CG animals potentially consuming pasture of higher quality. The results of the studies in Chapters 7 and 10 found CG ewes consumed a diet of higher quality than RG ewes in terms of
DMD, OMD and ME and are similar to the results of Waller et al. (2001) where lower quality forage was recorded in a tactically grazed improved pasture in comparison to a CG system. The higher diet quality is possibly three-fold; a result of restricting the location of the RG ewes within the landscape to areas having been rested from grazing with a higher ratio of stem to leaf material that showed reproductive growth earlier than CG pastures (Waller et al. 2001). Secondly, the unrestricted grazing of CG animals can result in grazing patterns within the landscape where animals affect the physiological developmental state of plant species and maintain areas of pasture in a higher quality vegetative state (as observed in Chapter 7). Thirdly, RG has been associated with differences in species composition with higher levels of nutrient rich pasture species such as *Trifolium subterraneum* being present within a CG system (Frame et al. 2002) as was observed within this study. The differences in ewe live weight and BCS and growth rate of lambs within this study were significant and greater knowledge of diet quality and selection of grazing animals within management systems is essential to understand the negative impact on production within a RG system and to improve the strategic use of these systems.

### 11.1.2 How variable is the composition and quality of the diet of individual sheep?

Research suggests that the inter-individual variation between animals of the same flock or herd in terms of diet selection, forage preferences, intake, grazing behaviour and nutrient requirements is considerable (Arnold 1964; Marten 1978). Consequently individual animal variation is an important consideration in experimental design to ensure the number of animals is sufficient to account for inter-animal variation (Prache et al. 2006). Current knowledge of individual animal variation within the studied pasture together with the use of non-invasive techniques is extremely limited.

The experiment in Chapter 5 provided a greater understanding of the individual animal variation of grazing sheep and identified the promising capabilities of estimating diet quality using non-invasive techniques of intensive pasture monitoring and faecal analyses. The experiment found differences in the average composition of the diet selected by two groups of grazing ewes were not reflected in the estimated DMD and ME of the consumed diets. It appeared the animals displayed ‘nutritional wisdom’ and selected a diet that met their similar nutrient requirements (Provenza 1995) from different diet compositions, although it must be acknowledged that the precision of the
faecal analysis is unknown and may have reduced the ability to identify inter-animal variation. The limited variation in diet quality between ewes within this study was an important finding in the development of sampling protocols for future experiments and it was concluded that a representative pooled faecal sample of a group of 25 animals grazing within a heterogeneous pasture may be obtained by the collection of individual samples from five animals. The required number of animals (five) to obtain a representative pooled sample is similar to the minimum number of sheep (four) required in a flock for grazing behaviour studies as recommended by Penning et al. (1993) and to account for individual variations in selection (Marten and Andersen 1975).

The animals within the two grazing groups consistently selected the green vegetative material from within the pasture that was associated with high DOMD and similar selection was observed in Chapters 6 and 7. A possible ‘cue’ and mechanism identified in Chapter 5 (in late winter) that may underlie selection was the green to dead ratio of forage of a pasture species and it is likely the similar diet quality of individual ewes and between groups of ewes was a product of this mechanism that was further investigated in subsequent experiments (Chapters 6 and 7).

11.1.3 How does change of season and pasture composition affect diet selection by sheep?

At present, knowledge of the diet selection of sheep grazing within native pastures and grasslands is limited to general influences of pasture quality, structural and chemical characteristics from observations in improved pastures and/or with simple compositions, with the exception of a study by Leigh and Holgate (1978). Selective grazing of a pasture by sheep is well recognised, but not fully understood and can have a profound effect on pasture botanical composition, management and animal production. The limited knowledge of diet selection and thus nutrition of ruminants grazing within native pastures and grasslands restricts the ability of livestock producers to make informed decisions about grazing systems and livestock management. A greater understanding of the composition of the diet of sheep grazing within heterogeneous pastures and the possible mechanisms underlying selection can provide more accurate information of the quality of the diet of grazing animals.

The experiments in Chapter 6 provided indications, using non-invasive methods, of the plant species selection and diet quality of sheep and the effect of changing availability and nutritive value of plants over time. The animals consistently selected green forage
from within the pasture and displayed strong selection and preference for green vegetative material that was typically higher in quality than the average available green pasture. The pattern of grazing and subsequently re-grazing preferred species over the duration of grazing, the disappearance of dead forage material from day 2 of grazing and the animals repeated uprooting/removal of small *Austrostipa* spp. plants from the pasture was consistent for the three study periods. The uprooting of *Austrostipa* spp. plants over time may be a means by which sheep subtly modify the botanical composition of a pasture, in particular within the LPZ of a landscape. In spite of the similarities between grazing periods the mechanisms underlying the selection of the green components of the major pasture species differed between seasons. Increased proportions of green herbage of a species was consumed in late winter (August – September 2010) in response to higher initial green to dead ratio of the major species and selection was poorly associated with other measured pasture quality parameters. In contrast in late summer (February 2010 and 2011) when the pasture contained a lower proportion of green forage, selection was influenced by the DOMD of the pasture species that may be a consequence of greater quantities of dead DM impeding the animal’s selection. The selection of green, typically vegetative pasture species by animals grazing within contrasting grazing systems (Chapter 7) was associated with the initial green to dead ratio of DM of a plant species in early spring and late summer and in different physiological states. The plant selection by ewes grazing within differing grazing systems was positively associated with the DOMD of green forage as a result of the selection of green vegetative material. As animals cannot perceive nutrients *per se* (Arnold, 1981) the primary cue for the animals’ selection and consumption of green forage in late summer then seems to be based on appearance, rather than a ‘memory’ of nutritive value.

The results of Chapter 6 together with the results of Chapter 5 from animals grazing within small plots suggested that more invasive techniques of oesophageal and/or rumen fistulation are not mandatory for investigating consumption patterns of grazing animals. The observed patterns of selection and the application of the methods were then investigated at a larger scale and discussed in subsequent sections.
11.1.4 How is diet selection and grazing behaviour of sheep and the physiological state of plants affected by grazing systems?

The interactions between grazing herbivores and plants are inherently complex and management decisions by producers can have a profound influence on plant-animal interactions. Grazing management systems seek to control the relationship between animals, plants and soil by regulating the number of animals and the duration and location of grazing animals, which affects an animal’s selectivity and distribution within an ecosystem (Beattie 1994). Studies comparing continuous and rotational grazing have demonstrated the complexity of plant-animal interactions (Jensen et al. 1990) with variable results and benefits recorded within different landscapes and pastures and between producers and researchers. Knowledge of the nutrition and diet selection of sheep grazing within native pastures and grasslands and the influence of grazing management systems is limited. A greater understanding of the plant-animal interactions and the influence of management decisions, in particular grazing management systems, is essential for the development of more efficient animal production systems.

The results in Chapter 7 indicate that grazing management systems can affect diet selection and grazing behaviour that in turn can have a profound effect on the physiological state of plants and animal production (Chapter 4). Similar to the findings in Chapters 5 and 6 the animals managed within the contrasting grazing systems were highly selective and consistently selected the green vegetative material from within the pasture that was of higher quality and digestibility than the average pasture and presumably highly palatable. The animals’ grazing activity was affected by their physiological state and the grazing system. When the ewes were lactating with lambs at foot both grazing treatments spent a similar proportion of time in an active state and grazed to the maximum time expected of approximately 12 h per day (Penning et al. 1993) in order to meet their nutrient requirements. However, the animals’ nutrient requirements were not being met and the animals within both grazing systems similarly lost weight. In contrast, in early autumn when the ewes were dry and not pregnant, CG ewes spent a greater (p < 0.001) proportion of their time inactive than active. The activity of the dry, not pregnant RG ewes was similar to when they were lactating with lambs. The extended grazing time of dry, not pregnant RG ewes in comparison to CG animals may be a result of the time required for the animals to select the green vegetative material from a pasture comprised of a lower proportion of green herbage.
than the previous study (in early spring). The greater activity of RG ewes in comparison to CG ewes in this study was in contrast to studies by Le Du et al. (1979); Baker et al. (1981); Walton et al. (1981); Heitschmidt et al. (1987a; 1987b) in sheep and Walker and Heitschmidt (1989) in cattle and observations by Jamieson and Hodgson (1979) in sheep and cattle all of which observed lower levels of activity of RG animals. The greater activity of RG ewes in this study was likely to be related to the physiological development and lower quality of the pasture in comparison to the CG system that resulted in the need to graze longer to try to satisfy their energy requirements.

Grazing management systems have been found to influence the species composition of a pasture. CG pastures are associated with greater quantities of high quality legume species such as *Trifolium subterraneum* in comparison to RG systems (Frame et al. 2002). Within this study the CG pasture recorded higher levels of *T. subterraneum* and the animals within the system appeared to establish highly utilised areas or ‘patches’ where the physiological development of the pasture was delayed as was the subsequent decline in forage quality associated with pasture maturation (Denney and Barnes 1977). The delayed development of forage within the HU areas of the CG system was consistent with the higher quality of pasture species collected from within the HU of the CG treatment across both study periods and the higher diet quality of CG animals (predicted OMD<sub>W</sub> and GrazFeed® predictions) reported in Chapter 7 and higher DMD and ME intake predicted from f/NIRS predictions in Chapter 10. The management of animals within a RG system with extended periods of rest and herbage accumulation (Chapman et al. 2003) was associated with a subsequent decline in forage quality and a lower diet quality and higher SR of the animals managed within the system. This result together with the lower forage and diet quality of animals managed within the RG system can be attributed to the lower animal production per head of RG ewes and lambs.

**11.1.5 How is a landscape utilised by grazing sheep?**

Grazed vegetation communities are heterogeneous in time and space (Chapman et al. 2007) and affect the landscape use and movement patterns of grazing animals. Spatially diverse landscapes together with the diet selectivity of sheep result in the uneven use of a landscape and the uneven distribution of nutrients that can have a profound effect on sward composition and production (Adler et al. 2001; Soder et al. 2007; Oom et al. 2008). The interactions between grazing herbivores and plants are inherently complex
and the effects of landscape variability and vegetation diversity on animal grazing behaviour are not well understood (Soder et al. 2007). A greater understanding of the landscape use of grazing animals within native pastures is essential to the use of grazing as a low-cost management ‘tool’ and in assisting livestock producers to make informed decisions about livestock management and the implementation of grazing systems within these complex pastures.

The GPS study and vegetation results (Chapter 8) indicate that the animals were not evenly distributed within the landscape and the activity and location of the animals was influenced by the animal’s physiological state (Bailey et al. 2001), climatic conditions (Dudzinski and Arnold 1979; Arnold 1982; Taylor et al. 1987) and the production zones and vegetation (Illius et al. 1992; Clarke et al. 1995; Edwards et al. 1996; Dumont et al. 2000; 2002; Ganskopp and Bohnert 2006) within the landscape.

During grazing the animals preferentially utilised the HPZ of the landscape (as well as the MPZ when lactating with lambs) and the use of these production zones may in part be explained by the positive associations of increased grazing activity and pasture with high levels of percentage green herbage (p < 0.001) during both experiments. The location of ewe grazing was positively associated with \textit{T. subterraneum, Lolium rigidum} and \textit{Microlaena stipoides} in late spring (when lactating with lambs at foot) and associated with \textit{Paspalum dilatatum, Holcus lanatus} and \textit{M. stipoides} in early autumn (when the ewes were dry and not pregnant). The association between high percentages of green forage (or high green to dead ratio of DM) support the observations of animal selection in early autumn (Chapter 6) and within the RG system at the site (Chapter 7) and suggest this is likely to be an important cue in the location and selection of grazing animals. The animals avoided grazing within the LPZ but preferentially rested and ruminated within this zone in late summer (when dry and not pregnant). Limited grazing within the LPZ may be attributed to the negative association identified between grazing and higher litter DM levels (p < 0.05) and the presence of \textit{Austrostipa} spp., \textit{Elymus scaber} and \textit{Austrodanthonia} spp. that were dominant within this zone of the landscape. The use of the lower productive areas including the mid- and upper-slopes and ridges during inactivity may be associated with trees and shelter (Taylor et al. 1987; Baumont et al. 2000; Taylor et al. 2011), innate predation risk (Stuth 1991) and the distribution of non-preferred plant species (Wang et al. 2010a).
The landscape use results (Chapter 8) support the proposal that in order to optimise landscape utilisation fencing should occur across slopes and according to productivity zones rather than the traditional fence lines that typically followed compass bearings (Dorrough et al. 2004a). The separation of HPZ and LPZ together with a flexible rotation system supports the management of landscapes proposed by the Scottish National Heritage (2010) that would allow managers to better utilise pasture resources and keep the HPZ for animals with high nutrient requirements that most need it. Similarly, the LPZ can then be grazed by dry stock and/or animals with low nutrient requirements where wool growth is more important than meat production. However, the recorded differences in diet selection and (grazing) activity across seasons and in response to different physiological states together with the recorded difference in animal production between CG and RG systems means the management of animals is far from simple and further investigation of the strategic use and flexible use of grazing systems is recommended.

11.1.6 Is the analysis of faecal samples an accurate and effective method to predict the diet quality of grazing sheep?
Currently determining the quality of the diet of sheep grazing heterogenous native pastures and grasslands has been limited by the lack of non-invasive methods. Researchers and managers have estimated diet quality based on variations in animal production, general comparisons of the quality and quantity of FOO and disappearance of pasture together with general nutritional information of harvested plant species. In this research where the aim was to allow unencumbered grazing by the sheep, it was decided to use published equations and other well established relationships to estimate the quality of diet intake (as well as direct estimates based on utilisation). The need to evaluate the published data, investigate the digestibility of forages in vivo, and develop predictive faecal chemistry equations and /NIRS calibrations became apparent. The animal house and laboratory studies were conducted after the fieldwork with the intention of using the derived functions to add to the analyses of the field studies.

Faecal indices have been used effectively to predict diet digestibility, quality and intake in sheep (Wehausen 1995; Boval et al. 2003; Wang et al. 2009), cattle (Holloway et al. 1981; Holechek et al. 1982a; Wehausen 1995; Lukas et al. 2005; Gibbs et al. 2002; 2004) and deer (Mubanga et al. 1985; Hodgman et al. 1996; Kamler and Homolka 2005).
The results in Chapters 9 and 10 indicate the potential of faecal chemical indices and fNIRS as tools for analysing the nutrition of grazing sheep, though highlight the need for the further development of faecal chemistry indices and/or fNIRS predictive calibrations. Unlike these previous studies, the results of an *in vivo* digestibility study of pasture harvested from the study site (Chapter 9) failed to identify strong correlations between faecal and diet parameters that are likely to be a result of the comparatively small number of diets and the overall narrow range of forage values within the study. The applicability of ‘generic’ predictive equations (Mahipala *et al.* 2009 and Wang *et al.* 2009) to the harvested pasture was evaluated and no relationship (p > 0.05) was identified between the predicted and observed values in terms of OMD<sub>W</sub> and ME<sub>M</sub>. The recorded discrepancies between the observed and predicted OMD and ME of the diets used in Chapter 9 are likely to be a consequence of the low quality of the harvested pasture being outside of the range of pasture quality values of the feeding studies from which the predictive equations were derived. However, the predicted OMD<sub>W</sub> values when compared with the estimated diet quality of animals grazing fresh pasture within small plots and contrasting grazing systems (Chapters 7 and 10) (that was of higher quality (OMD and ME) than the dried pasture) followed the same trend as the GrazFeed<sup>®</sup> predicted values and provide a qualitative, rather than quantitative method of comparing the diet quality of grazing animals. In contrast, the predicted ME<sub>M</sub> values were considered to be inaccurate and unsuitable for use within the studied native pasture and grassland as the predicted values did not reflect the estimated values of GrazFeed<sup>®</sup> or the observed differences in animal production between the grazing systems (Chapters 4 and 7).

Faecal NIRS predictive equations were developed (Chapter 9) to estimate the quality of the diet (DMD, OMD and to a lesser extent ME) of sheep. The results of Chapter 10 indicated the values predicted from fNIRS followed similar trends to the GrazFeed<sup>®</sup> predictions as well as predicted OMD<sub>W</sub> values and provided a qualitative method of comparing the quality of the diet of grazing animals. Whilst the indirect prediction and qualitative analysis of the diet quality of grazing animals from fNIRS is possible the results of these studies have highlighted that the application of fNIRS predictive equations (and faecal chemistry indices) are limited outside of the range of the original calibration database.
The analysis of the diet quality of grazing animals using non-invasive faecal analysis is possible and the development of a large calibration database is essential and involves substantial investment. Where the development of a database is possible, establishing a \textit{fNIRS} database should be a priority as a result of the cost-effective, rapid analysis without the need of reagents or potential safety hazards (Mark \textit{et al.} 2002). The development of a \textit{fNIRS} database would assist producers and researchers to gain greater knowledge of animals diet quality and provide a clear and reliable means of decision making in terms of the management of grazing animals.

11.2 Strengths and weaknesses of the study
The project design was established around the criteria of non-invasive methods of examining the selection and quality of the diet of grazing animals. Previous studies have investigated diet selection and quality of grazing animals at a large scale using invasive techniques. The lack of non-invasive methods applicable to complex heterogeneous pastures resulted in the need to develop and test applicable pasture monitoring methods to be used in conjunction with ‘generic’ predictive equations. This study investigated the diet selection of grazing animals using non-invasive techniques at a meso-scale level and the multi-faceted nature of the study provided information on how selection and subsequent quality of the diet of grazing animals is affected by seasonal changes in pasture composition and quality as well as management strategies. These results will assist managers to improve the understanding and management of plants and animals within the region.

The complex nature of grazing systems and the scale of the experiments in this study meant that numerous factors that may have influenced the results at the larger scale were not able to be monitored sufficiently. These included soil variability, microclimate effects within the landscape and social interactions of the animals. However, the major influences of management, climate and pasture composition (within small plots, RG system and areas within the CG system) were monitored adequately to put forward explanations of the results. As this study contributed to the larger EverGraze research many of the larger-scale factors within the landscape that were unable to be monitored in this study will be addressed in the final EverGraze report.

There were a number of weaknesses to the project design including the inability to accurately measure individual animal intake and the lack of an accurate and precise method of comparing diet quality of grazing animals. However, the examination of
‘generic’ faecal predictive equations highlighted the limitations of the application of these equations and the need to develop these methodologies. These limitations decreased the precision of the study; however, the use of faecal chemistry indices and fNIRS together with intensive pasture monitoring and GPS tracking of sheep provided useful information about the selection and diet quality of sheep grazing a native grassland in the Central Tablelands of NSW and has implication for the management of animals within the region. Dead DM is the opposite of the greenness of a pasture that was identified as a primary cue and mechanism underlying grazing. Whilst the quantity of dead DM was estimated in this study, the results of the study may be enhanced by the assessment of the nutritive value of dead DM of a pasture. As a result it is recommended the influence and nutritive value of dead DM within a pasture is examined in future studies.

11.3 Management implications

The limited knowledge of linking diet selection and quality to visual estimations of pastures and thus nutrition of ruminants grazing within native pastures and grasslands restricts the ability of livestock producers to make informed decisions about grazing systems and livestock management. The greater understanding of the composition of the diet of sheep grazing within heterogeneous pastures and the possible mechanisms underlying selection from this study has provided more accurate information of the quality of the diet of grazing animals.

The results of Chapters 4 and 7 indicate the significant impact grazing systems can have on animal production as well as the physiological development and quality of plants that is not simply a SR effect. The study identified how grazing animals utilise a landscape and possible factors underlying observed differences in animal production between CG and RG systems. One of the primary cues that may underlie the specific selection of pasture species by sheep grazing within the studied native pasture was the green to dead ratio of DM (or greenness) of a species that affects the movement patterns of grazing animals within a landscape.

‘Free-ranging’ animals are not evenly distributed within a landscape and the activity and location of the animals was influenced by the animal’s physiological state, climatic conditions and the production zones and vegetation within the landscape. The recorded use of the LPZ during inactivity may be associated with the location of trees and shelter and result in the establishment of sheep camps within the higher parts of the landscape,
a high concentration of faeces and an uneven distribution of nutrients that in turn influences vegetation and future use of the area. The consistent strong selection of green vegetative forage by animals from within a pasture if unmanaged may result in a decline in the species over time and potentially reduce pasture quality (Mott 1987; Archer et al. 1993). However, if the observed repeated defoliation of plants occurred within a ‘correctly stocked’ CG system the re-grazing of plants may provide a means to maintain diet quality (by changing the physiological development stage of the plants) as a result of animals ingesting predominantly green vegetative i.e. minimal stem forage.

Managing the location and duration of animal grazing via the use of RG systems does provide a means of managing the FOO to the animals and as the results of this study indicate may provide advantages through summer and autumn. Restricting the location of animals within a landscape may result in the benefits of; increased landscape utilisation and nutrient distribution and prevent the heavy utilisation of preferred plants; however, the ‘cost’ will likely be in individual animal performance. The separation of HPZ and LPZ together with flexible rotations would allow mangers to keep the HPZ for animals that most need it and will deliver the best financial returns and the LPZ could then be used for dry stock and/or animals with low nutrient requirements where wool growth is more important than meat production. However, the management of animals within an intensive RG system is far from simple. In order to optimise per head animal production within intensive RG, the animals should be moved before plants are re-grazed, similar to the recommended grazing period of three days of Fulkerson and Slack (1994) within dairy systems to minimise the re-grazing of ryegrass and optimise plant survival.

The use of greenness of a species may provide an important indication of where animals would be likely to graze within a landscape and obtain a large amount of their nutrients from. If the greenness of a species is determined and monitored by a producer using GIS and NDVI, it may be a trigger in the management of animals within intensive RG systems. Within an intensive RG system the greenness of a species may be a management trigger, for example the high utilisation of dead material may be restricted to periods of low animal requirements or by classes of livestock with lower requirements (e.g. dry ewes or wethers) followed by utilisation of only green leaf by stock with higher requirements and/or during high requirement periods. In practice this may involve the implementation of a leader/follower rotation with pregnant ewes
leading dry ewes or weaned lambs leading their mothers in early summer. A leader/follower system would ensure a short-grazing period and allow the lead group to select the high quality green forage and the remaining pasture with proportionally greater dead DM would be utilised by the stock with lower energy requirements. In the same way if climatic conditions together with the duration of grazing results in the pasture composition of a high quality paddock being dominated by dead DM, the pasture may be grazed by stock with lower nutrient requirements in order to create a pasture with greater green leaf material for stock with higher nutrient requirements.

The greater understanding of the composition of the diet of sheep grazing within heterogeneous pastures and the possible mechanisms underlying selection from this study has provided more accurate information of the quality of the diet of grazing animals. However, the diet selection, quality and intake of grazing animals within heterogeneous landscapes remains one of the least understood aspects of animal production and management strategies. A greater understanding of the diet selection and intake of grazing animals may be obtained by the use of the developed non-invasive methodologies and enhanced by the development of a double-sampling hand-plucking technique to mimic the selection and intake of grazing animals that could be evaluated via the use of the decision support tool GrazFeed® and dietary markers. The future use of faecal analysis for the quantitative analysis of diet quality relies upon in vivo digestion studies of fresh native pasture from within the Central Tablelands region over a variety of seasons and growing conditions. The development of an/NIRS database should be a priority as the cost-effective, rapid analysis without the need of reagents or potential safety hazards (Mark et al. 2002) would provide a clear and reliable means of enhancing the decision making of producers in the management of their grazing animals.

11.4 Conclusion

The most important outcomes from this research are: the identification of a primary cue, the green to dead ratio of DM underlying the selection of grazing animals; the seasonal flexibility of selection; patterns of landscape use by unrestrained grazing animals; and the effect of grazing systems on animal production and the physiological state of plants.

The results of this study support the existing findings that RG systems can increase the landscape utilisation and SR, at the cost of individual animal performance. In order to enhance landscape utilisation and animal production it is necessary to have non-invasive
methods of examining diet selection and quality of grazing animals in all pastures and environments, because diet quality is the major determinant of animal production. This study has demonstrated that it is possible to examine the selection and thus composition of the diet of grazing animals using intensive pasture monitoring and the promising application of f/NIRS and faecal chemistry predictive equations to allow qualitative assessment and comparison of diet quality of grazing sheep in extensive situations. The findings of this research have drawn attention to the need for further investment and research and the development of an applicable f/NIRS database to pastures within the studied region to allow quantitative comparisons to be made. None-the-less, these results suggest that more invasive techniques of oesophageal and/or rumen fistulation are not mandatory for investigating consumption patterns of grazing animals.

Understanding the selection and subsequent composition of the diet of grazing sheep is vital to the improved management of animal production and natural resources within a landscape. The results obtained in this research have contributed to a more informed understanding of the flexibility of pasture species selection within an animal’s diet and the possible mechanisms of the percentage green within a landscape and the green to dead ratio of DM underlying the diet selection and landscape use of grazing animals.

The implementation of more intensive grazing management systems is widespread within the Central Tablelands of NSW, although essential knowledge of the effects of management actions on plants and animals are limited. The outcomes of this research identified the impact restricting animals within a landscape can have on animal activity, diet selection and quality, animal production and the physiological state of plants. The information on the effects of grazing systems will assist in assessing the implementation and management of grazing systems within heterogenous landscapes.

The potential management recommendations to enhance the productivity of animals managed within an intensive RG system within the region are:

i) To optimise animal production grazing animals should be moved before plants are re-grazed; and

ii) The use of greenness of species may indicate where animals would be likely to graze within a landscape and provide a management trigger in grazing management systems. For example the high utilisation of dead material may be restricted to periods of low animal requirements or by class of livestock using a
leader/follower system. A greater understanding and awareness of the greenness of species and pastures would allow a short-grazing period by stock with higher nutrient requirements (e.g. pregnant ewes or weaned lambs) to select high quality green forage. Subsequently, the remaining pasture with a higher proportion of dead DM would be utilised by animals with lower requirements (e.g. dry ewes or wethers).

A number of important issues have been raised in relation to the precision of determining the diet selection and quality of animals grazing within heterogeneous landscapes and pastures. The precise prediction of a grazing animal’s diet selection, intake and quality are not yet possible using non-invasive techniques in diverse native pastures and the need for on-going research and development of these methodologies cannot be overstated.

The limited knowledge of diet selection and thus nutrition of ruminants grazing within native pastures and grasslands restricts the ability of livestock producers to make informed decisions about grazing systems and livestock management. The pursuit of a greater understanding of the composition of the diet of sheep grazing within heterogeneous pastures and the possible mechanisms underlying selection is essential to provide more accurate information of the quality of the diet of grazing animals.
Chapter 12. References


Allden WG (1979) Feed intake, diet composition and wool growth. In 'Physiological and environmental limitations to wool growth'. (Eds JL Black and PJ Reis) pp. 61-78. (University of New England Publishing Unit: Armidale)


Arnold GW, Dudzinski ML (1978) 'Ethology of free-ranging domestic animals.' (Elsevier: Amsterdam)


Breakwell E (1923) 'The grasses and fodder plants of New South Wales.' (Department of Agriculture: Sydney, NSW).


Commonwealth of Australia (2007) 'Australian natural resources atlas- high rainfall zone.' (Australian Department of Sustainability, Environment, Water, Population and Communities: Canberra)


Court J, Webb Ware J, Hides S (2010) 'Sheep farming for meat and wool.' (CSIRO publishing: Collingwood Victoria, Australia)


Curtis A, O'Brien G (1994) 'Pasture management for dairy farmers.' (Department of Agriculture, Victoria)


Forbes JM (2007) 'The voluntary food intake and diet selection in farm animals.' (CAB international: Oxfordshire, UK).


Gangstad EO (1964) Physical and chemical composition of grass sorghum as related to palatability *Crop Science* 4, 269-270.


Graham NM (1964) Utilization by fattening sheep of energy and nitrogen in fresh herbage and in hay made from it. Australian Journal of Agricultural Research 15, 974-981.


Holmes Sackett Pty Ltd. (2011) Aginsights: knowing the past shaping the future. (Holmes Sackett and Associates Pty Ltd, Wagga Wagga, Australia).


Isbell RF (1996) 'The Australian soil classification.' (CSIRO: Collingwood, Australia)


Leigh JH, Holgate MD (1978) Effects of pasture availability on the composition and quality of the diet selected by sheep grazing native, degenerate and improved pastures in


243


Minson DJ (1990) 'Forage in ruminant nutrition.' (Academic Press: San Diego)


Noad B (2003) 'PROGRAZETM Profitable, sustainable grazing.' (NSW Agriculture: Dubbo, Australia)


NSW Agriculture (1983) 'Summary of feed composition.' (Glenfield, NSW Australia)


OPUS (2006) Bruker Optik GmbH Ettlingen, Germany. 5.5 Build: 5.5, 0, 72.


Srivastava LM (2002) 'Plant growth and development: hormones and environment.' (Elsevier Science: USA)


Suiter J (1994) Body condition scoring of sheep and goats. Farmnote 69. Department of Agriculture and Food Western Australia, Perth, WA


Thompson AN, Ferguson MB, Gordon DJ, Kearney GA, Oldham CM, Paganoni BL (2011b) Improving the nutrition of Merino ewes during pregnancy increases the fleece weight and reduces the fibre diameter of their progeny’s wool during their lifetime and these effects can be predicted from the ewe’s liveweight profile. *Animal Production Science* **51**, 794-804.


Tothill JC, Hargreaves JNG, Jones RM (1992) 'BOTANAL a comprehensive sampling and computing procedure for estimating pasture yield and composition. I. Field sampling.' CSIRO Australia.


Weston R.H. (1966) Factors limiting the intake of feed by sheep I. the significance of palatability, the capacity of the alimentary tract to handle digesta and the supply of glucogenic substrate. *Australian Journal of Agricultural Research* 17, 939-954.


Weston R.H. (1968) Factors limiting the intake of feed by sheep III. the mean retention time of feed particles in sections of the alimentary tract. *Australian Journal of Agricultural Research* 19, 261-266.


Appendix A. Evaluation of Passage Rate of Digesta

A.1 Introduction

The use of faecal analyses to estimate diet quality has great potential in studies of grazing animals as large numbers of easily obtained samples may be collected without disruption to grazing animals (Lukas et al. 2005). However, in order to obtain representative samples of an animal’s diet over short periods of time knowledge of the rate that an ingested food passes through an animal and is expelled in a grazing animal’s faeces (the passage rate of digesta) is required.

The greater proportion of the digestion of forages and feeds typically occurs in the reticulo-rumen of sheep (Weston 1968) where the breakdown of feeds occurs through chewing and rumination together with digestion by micro-organisms (Forbes 2007). The rate of disappearance of an ingested food within the gastro-intestinal tract of sheep is affected by the outflow of digesta from the reticulo-rumen which is influenced by the size of the reticulo-omasal orifice that food particles must be small enough to pass through (Campling 1964). The level of reticulo-rumen fill is also linked with an animal’s intake (Blaxter et al. 1961; Weston 1966). The reduction in food particle size occurs through chewing and rumination, and this efficiency of chewing and rumination varies with the physical and chemical properties of forages (Campling 1964).

The average retention time of particles (average passage rate of digesta) has been estimated from pen-feeding trials using a variety of forages and in one study, grazing animals. Weston (1968) investigated the average retention time of feed particles in the digestion tract of sheep consuming chopped straw and lucerne (alfalfa) hay. The average rate of passage of coarse particles was estimated as 57.5 h and the retention time of lucerne was substantially less than straw. Huston et al. (1986) compared the dynamics of digestion in ruminants and estimated the average rumen retention time of undigested particles as 35.5 h in sheep consuming coarsely ground sorghum hay (in an early vegetative and early reproductive growth phase) using an insoluble marker (erbium chloride). The authors also investigated, using an insoluble marker (ytterbium nitrate), the passage rate of digesta in sheep grazing a native range in Texas seasonally and estimated the average retention time in autumn (fall) and spring as 40.4 h and 26.4 h, respectively. However, the authors conceded the insoluble markers together with the method of administration (directly into the rumen in the case of ytterbium nitrate) are known to estimate faster rates of passage. Simao Neto et al. (1987) evaluated the
recovery of pasture seeds ingested by ruminants consuming a diet of lucerne chaff (80%) and milled wheat grain (20%). A known quantity of pasture seeds were fed with milled wheat grain and in sheep the highest recovery of seeds occurred on day 3 and 50% of seeds were recovered in the faeces at 61.7 h. The passage rate and rumen fermentation patterns of sheep and goats fed high quality diets of alfalfa hay and varying quantities of sugar beet pulp and oat hay were evaluated by Molina Alcaide et al. (2000). They dosed a marker (chromium) directly into the rumen during feeding and estimated the average retention time of digesta in the rumen of sheep as 40 h. Slower outputs were associated with diets containing sugar beet pulp and/or oat hay.

The common method throughout the studies by Weston (1968); Simao Neto et al. (1987); Molina Alcaide et al. (2000) was the feeding of lucerne hay known to be a highly digestible forage and the pre-cutting and/or grinding of the forages prior to feeding, that also occurred in the pen-feeding study by Huston et al. (1986). The study in grazing animals (Huston et al. 1986) did not provide details of the forages consumed by the animals. All of the studies consistently highlighted the confounding factors in the passage rate of digesta of forages as well as the use of markers. Thus the aim of this experiment was to examine the passage rate of digesta in sheep grazing small plots within a native pasture over a number of days by examining the quality of the diet of the animals using faecal chemistry indices.

A.2 Materials and methods

A.2.1 Site location and experimental design

Four replicate plots, 0.08 ha (20 m x 40 m), were established within a native grassland in February 2010 at the EverGraze Central Tablelands Proof Site.

The plots were paired based upon available forage and similar botanical compositions (plots 1 and 3 and 2 and 4, respectively were paired). The four plots were grazed by two groups of 10 dry Merino ewes (CentrePlus®) at a stocking rate of 125 DSE/ha. The first two plots were grazed for four days, after which the animals were moved to two separate overflows areas adjacent to the plots before subsequently grazing plots 2 and 4 for five days.

Prior to grazing plots 1 and 3 the animals were restricted to grazing the overflow area adjacent to the plots that contained substantially less green feed and available FOO. This was designed to potentially provide a contrast in the animal’s diet quality prior to
grazing the small plots. The animals commenced grazing the plots at 0700 h and the first daily faecal sample was collected 9 h later at 1600 h. All subsequent faecal samples were collected at the same time each day for the duration of each plot grazing.

**A.2.2 Faecal sample collection**

Daily, fresh (composite) faecal samples were collected from pasture at the same time each day from each plot (1600 h for plots 1 and 2 and 1630 h for plots 3 and 4). Each composite sample comprised five faecal samples (presumably representing five sheep). Faecal collection methods and analysis are described in Chapter 3, sections 3.2.2.1 and 3.5.2.

**A.2.3 Faecal analysis**

The analysis of faecal matter included \( f_N \), \( f_{NDF} \), \( f_{ADL} \) and \( f_{Ash} \). Refer to Chapter 3 section 3.5.2 for details of analytical procedures.

**A.2.4 Estimated diet quality**

The animal’s dietary OMD were estimated using an equation developed by Wang et al. (2009). For clarity of presentation the derived values are referred to as OMD\(_w\). Refer to section 3.6.2 for details of the derived equation and Chapters 5 and 9 for further information on the application of the derived equation to the studied pasture as a qualitative (rather than quantitative) method of comparison.

**A.2.5 Passage rate of digesta**

The passage rate of digesta was inferred from the evaluation of the animal’s estimated quality of diet over time and the location of the animals grazing.

**A.3 Results**

At the outset the pasture biomass was 2269 kg DM/ha, consisting of 41% green herbage. The pasture was dominated by *Microlaena stipoides* (46%) and *Austrodanthonia* spp. (22%), with lesser contributions by *Austrostipa* spp. (7%), *Hypochaeris radicata* (6%), *Juncus* spp. (6%), *Elymus scaber* (4%), *Acetosella vulgaris* (1%) and dead *Lolium rigidum* (1%) and *Bothriochloa macra* (> 1%). Following grazing the biomass of the pasture was reduced to 1510 kg DM/ha, with the biomass of green *M. stipoides*, *Austrodanthonia* and *H. radicata* being reduced (p < 0.001). The biomass of dead *M. stipoides*, *Austrodanthonia* spp. and *L. rigidum* and the green biomass of *E. scaber*, *Austrostipa* spp. and *A. vulgaris* was also reduced (p < 0.05).
A.3.1 Diet selection
The average change in species biomass and the plant species selection over time for all four plots are reported in Chapter 6 section 6.3.2.1 and section 6.3.3.1, respectively. In summary at the outset of grazing the average biomass within the plots was 2269 kg DM/ha, consisting of 41% green herbage. The animals initially selected the green vegetative material within the pasture and consumed a diet dominated by green forage with negligible proportions of dead material (≈ 1.4 % of the diet) on the first day of grazing. Over time the animal’s intake of green forage declined and the consumption of dead forage components increased to 28% on day 2 and approximated 52% of the animal’s intake by day 4 and day 5 of the first and second plot grazing, respectively. As a consequence the diet quality of the animals estimated from the plant species selection and pasture quality analysis (Chapter 6 section 6.3.4.1) was highest on the first day of grazing before subsequently declining over time.

A.3.2 Diet quality over time
The estimated OMDW of the diet of the ewes over time is shown in Figure A.1. The OMDW of the animal’s diet during the first plot grazing increased over the first 2 days of grazing plots 1 and 3 and peaked on day 3 before declining on day 4. During the second plot grazing the OMDW of the diet increased over day 1 to 4 and was highest on day 4 of grazing, before declining on day 5. The trend in the diet quality of the ewes over time was similar between the two grazing groups and plots.
Figure A.1. Estimated OMD\textsubscript{w} of the diet consumed by two groups of dry ewes grazing paired small plots over time. Plots 1 and 2 (purple); plots 3 and 4 (green)

A.4 Discussion

The observed peak in diet quality that occurred on day 3 and 4 of the first and second grazing of the plots, respectively may be associated with the animals commencing the grazing of the plots and consuming higher quality forage than the previous and/or subsequent days. It appears the trend in diet quality over time reflects the movement of the animals from an area of lower quality forage (overflow area) to an area of higher quality forage (small plots) and also the observed diet selection and estimated quality of the animals grazing the plots. A limitation of the method was the collection of faeces only occurring when the animals were grazing the studied plots.

From these results the passage rate of digesta can be inferred as the animals commenced grazing the plots at 0700 h and the first faecal samples were collected at 1600 h (9 h later). The peak in diet quality on day 3 of the animals grazing the first plot occurred at approximately 57 h post the animals first entering the plot. The maximum OMD\textsubscript{w} recorded by the animals during the second plot grazing on day 4 is approximately 81 h post the animals commencing grazing the plot. The average time the highest diet quality of the animals was recorded following entering a cell was 69 h. The inferred passage rate of digesta from the first plot grazing (≈ 57 h) is similar to 57.5 h recorded by
Weston (1968) in sheep consuming chopped straw and lucerne hay and 61.7 h observed by Simao Neto et al. (1987) to recover 50% of pasture seeds ingested by sheep consuming a diet of lucerne chaff and milled wheat. The similar time of passage rate was unexpected due to the pre-feeding treatment (chopping, chaffing and milling) of the experimental feeds and the higher digestibility and quality of lucerne than the studied native pasture. The extended period of time recorded in the second grazing period in comparison to the first is not easily explained. The difference may in part be explained by the interval of faecal sampling (once daily) being too long to identify an earlier peak in diet quality that may have occurred. Furthermore, the extended passage rate of digesta may also be related to the possibly lower quality and quantity of forage in the overflow area post the previous grazing with insufficient time for pasture regrowth. It is recommended future faecal sampling when investigating the passage rate of digesta occur at shorter intervals of 6 h and it is also recommended future faecal sampling occurs for at least 3 - 4 days post the animals grazing a studied pasture.

**A.5 Conclusion**

The cycle of moving two groups of dry ewes from an area of lower quality (overflow area) to an area of higher quality forage (small plots) was reflected in the estimated diet quality of animals and was in agreement with the observed selection and estimated quality of the diet of the animals grazing the plots over time. The average inferred passage rate of digesta in sheep grazing the studied native pasture was 69 h (range 57.5 h to 81 h) and considering the lower digestibility of native pasture in comparison to chopped and chaffed lucerne hay and milled wheat the average rate of 69 h appeared to be sensible. Future faecal sampling when investigating the passage rate of digesta needs to occur at shorter intervals and it is recommended that daily faecal sample collection is conducted four days post animals grazing a studied pasture to account for the passage rate of digesta.
Appendix B. Development of the Grazing Rating Index

B.1 Introduction
Determining the diet selection of grazing animals is inherently difficult and a trade-off exists between obtaining accurate information and interfering with the normal grazing behaviour of an animal. The botanical composition of a grazing animal’s diet may be estimated using one or a number of techniques in combination.

A six-point grazing rating index was designed to identify the plant species consumed by sheep grazing within heterogenous native grassland and the extent to which each species within a quadrat was grazed. The daily grazing rating index was used in conjunction with direct visual estimation (Campbell and Arnold 1973) pre- and post-grazing to estimate the consumption, diet selection and quality of grazing sheep over time. The index ranged from 0 (no grazing) to 5 (severe grazing with minimal stem material and the base of a plant remaining). The initial values of the index described the consumption of a plant with respect to the plant parts consumed and estimated the percentage of plant material consumed in broad increments (Figure B.1).

![Grazing rating index](image)

Figure B.1. Initial grazing rating index to identify plant species and parts eaten by grazing animals.

The aim of this study was to examine the parameters of the grazing rating index by measuring and weighing marked plants and tillers within small plots grazed by dry Merino ewes. A secondary aim was to refine the parameters of the index to be used as a methodology to identify the selection of grazing animals and the proportion of a plant species consumed by the animals.
B.2 Materials and methods

B.2.1 Site location and experimental design
The experiment was conducted from 9th February to 28th February 2011 at the EverGraze Central Tablelands Proof Site, at Panuara (33°27’S, 148°33’E) in New South Wales.

Four replicate plots, 0.08 ha (20 m x 40 m), were established within a native grassland in October 2009. The plots were paired based upon available forage and similar botanical compositions (plots 1 and 3 and 2 and 4, respectively were paired) and were grazed by two groups of 10 dry Merino ewes (CentrePlus®) at a stocking rate of 125 DSE/ha over a period of seven days. Plot 3 was not grazed during this study due to lambs grazing the plot a week prior and the resulting inadequate biomass of the plot. Refer to Chapter 6, sections 6.2.2 and 6.3.2 for further information on the animals and pasture assessment methods.

B.2.2 Identification and location of marked plants and tillers
Prior to the commencement of grazing 36 plants within each plot were located within each plot (plants were located 0.5 m from each established permanent pasture assessment plot) by a single operator. The plant species, number of leaves, stage of growth and number of tillers (for grasses) was recorded and the plant was marked using wire rings similar to Hodgson (1966). The plant species included native grasses (C3) and introduced forbs: Acetosella vulgaris, Austrodanthonia spp., Austrostipa spp., Elymus scaber, Holcus lanatus, Hypochaeris radicata and Microlaena stipoides.

The height of each plant was recorded from the base of the plant (at ground level) to the end of the upright plant. In grass species the height included the extension of the final leaf. To estimate the initial dry weight of each marked plant a paired (or ‘matching’) plant of the same height with similar numbers of leaves and the same number of tillers was located within the surrounding area. The ‘matching’ plant was cut at ground level using hand-operated pasture shears and placed in a paper bag prior to drying (at 60°C for 72 h) and weighing.

B.2.3 Assessment of marked plants
During each day of grazing the plants were assessed by the same operator and assigned a grazing rating value depending upon whether the plant had been grazed and the extent
of grazing as outlined in Figure B.1. The height and number of leaves of each plant were measured and if grazing was evident the plant parts (i.e. leaf and/or stem) removed were recorded.

At the end of grazing the marked plants were assessed and harvested at ground level using hand-operated pasture shears and placed in a paper bag prior to drying and weighing.

**B.2.4 Statistical analysis**

The relationship between the proportion of biomass and plant height removed and the final grazing rating was analysed using regression analysis in Genstat® (13th edition, Hemel Hempstead United Kingdom).

**B.3 Results**

A strong linear relationship ($p < 0.001$) was established between the consumed plant biomass and the estimated grazing rating ($R^2 = 0.92$; residual standard error = 0.09) (Figure B.2).

![Figure B.2. Relationship between the proportion of consumed plant biomass and the estimated grazing rating.](image)
The relationship calculated the consumed proportion of biomass of a plant species (Y) as:

\[ Y = 17.73x \]

The plant parts consumed by the animals and associated with each grazing rating value are outlined in Table B.1. The plant parts removed were identified for grazing rating values of one to three however, for grazing ratings of four and five only the plant material remaining was identified.

**Table B.1.** Plant parts consumed by grazing animals for each grazing rating value

<table>
<thead>
<tr>
<th>Grazing rating</th>
<th>Consumed plant parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No grazing evident</td>
</tr>
<tr>
<td>1</td>
<td>Tips of leaves</td>
</tr>
<tr>
<td>2</td>
<td>Tops of leaves and tillers</td>
</tr>
<tr>
<td>3</td>
<td>Leaves tillers and stem material</td>
</tr>
<tr>
<td>4</td>
<td>Stem and minimal leaf material remain</td>
</tr>
<tr>
<td>5</td>
<td>Only stem and base of plant material remain</td>
</tr>
</tbody>
</table>

A new grazing rating index was calculated using the derived equation, grazing rating increments of 0.5 together with the consumed plant parts for each grazing value and shown in Figure B.3. The grazing rating of one was assigned the minimum value of one and the maximum value of 21% was calculated to incorporate a grazing rating of 1.5. Similarly a grazing rating of two was assigned the minimum value of 22 % (one greater than the maximum of a grazing rating of one) and a calculated maximum of 39 % to include a grazing rating of 2.5.

**Figure B.3.** Grazing rating index to identify plant species and parts eaten by grazing animals.
**B.4 Discussion**

A strong correlation ($R^2 = 0.92$) was identified between the proportion of plant biomass consumed by grazing animals and the estimated grazing rating values. The plant parts associated with each grazing rating value were also identified. The results indicate that the values of the index are well related to the proportion of biomass consumed by grazing animals and the derived grazing rating index (Figure B.3) is an effective means of estimating the percentage of plant biomass of a plant species consumed by grazing animals within the studied native pasture. However, further investigation of these relationships by different operators and in other pastures is recommended to determine the applicability of the index to other operators and pastures.

**A.5 Conclusion**

The results indicate the values of the grazing rating index and the proportion of plant biomass consumed are well related and may be used to identify the plant species selection of sheep grazing within the studied native pasture. However, further research is needed to determine the applicability of the index to other pasture compositions and operators.