Investigations of pasture and grazing management within farmlet systems on the Northern Tablelands of New South Wales

Libuseng Matilda Mpiti-Shakhane
B.Sc. Agric. (Honours) (Lesotho)
M.Sc. (Malawi)

A THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
UNIVERSITY OF NEW ENGLAND
May 2006

Images of some Cicerone farmlet paddocks over a range of seasons

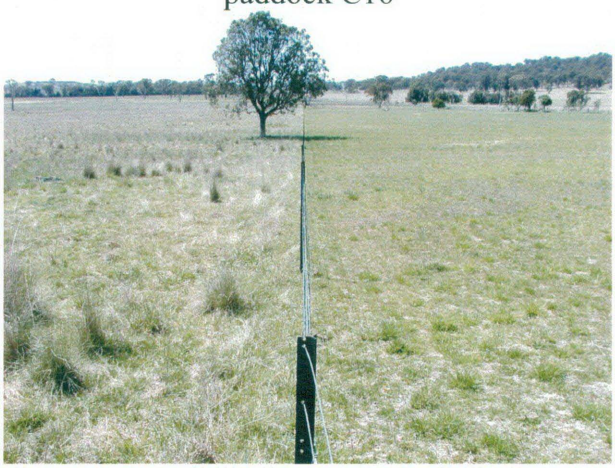
Mix sheep and cattle grazing on paddock C4

Patch grazing observed on paddock B5

Field day visit to paddock A6

Herbage accumulated after long rest on paddock C16

The author (RHS) explaining technique to Cicerone members



Paddock C5 (left); paddock A3 (right)

DECLARATION

I declare that the substance of this thesis is the result of my own original work. Where references have been made to the published literature, the authors have been acknowledged accordingly in references. This material has not been presented previously to the University of New England or any other tertiary academic institution for the award of the degree.

[redacted]

Libuseng Matilda Mpiti-Shakhane

Dedication

This thesis is dedicated to my beloved parents, Maria and John Mpiti, who did not live long enough to see my achievements. In memory of my mom, who valued education so much that she wanted all her seven children to go to university.

Summary

In temperate regions of New South Wales, Australia, there is increasing evidence of pasture decline, especially of deep-rooted, perennial pastures. Due to the high costs of farm inputs and of re-establishing pastures, grazing management has recently been investigated as a useful management tool to maintain production levels over the long-term - for the benefit of both pasture and animal. There is however inadequate knowledge of how to use grazing management to match the nutritional requirements of grazing animals with a variable pasture supply.

This study was conducted at the CSIRO's Chiswick property, Armidale as part of the Cicerone Project - a producer-led research and adoption group which commenced a whole-farmlet study of grazing enterprises in July 2000. The overall aim of the farmlet study was to assess the relative sustainability and profitability of three farmlet systems varying in farm inputs and grazing management. The main purpose of the study reported in this thesis was to examine the balance between both supply of feed (mostly from pastures) and the demand for feed by the range of livestock able to be supported by each farmlet. The data collected allowed the calculation of a 'partial' metabolisable energy balance (the estimate of a 'partial' balance was based on pasture growth and supplements and animal requirements without taking into account utilisation of the standing herbage mass, due to insufficient measurement of intake) as a means of comparing the relative match between supply and demand over time on each farmlet.

The two primary hypotheses tested in this thesis related to the effects of two different farm management strategies (high inputs or intensive rotational grazing) to provide superior pasture and/or animal outcomes compared to a moderate-input, flexible grazing system which is typical of the region.

The three farmlet systems, each of 50 ha, were farmlet A (high input system), farmlet B (typical district practice) and farmlet C (intensive rotational grazing). The control treatment, Farmlet B, represented the most common grazing system employed by graziers on the Northern Tablelands of New South Wales. The farmlets differed both in the level of inputs applied (pasture and fertiliser) as well as the system of grazing management employed.

On farmlet A, the fertiliser strategy aimed at achieving target levels of 60 and 10 mg kg^{-1} of soil phosphorus and sulfur respectively. On farmlets B and C, the target levels were 20 and 6.5 mg kg^{-1} of soil phosphorus and sulfur respectively. In addition, the pastures on farmlet A

were planned to be re-sown where necessary to provide a farmlet where all paddocks were dominated by deep-rooted, fertiliser-responsive perennial grasses, together with persistent legumes.

Two forms of grazing management were investigated: on farmlets A and B, flexible grazing according to PROGRAZE principles, was attempted. This involved moving the livestock, usually as 4 or 5 mobs, over the 8 paddocks of each farmlet according to the livestock condition and the availability of sufficient herbage mass and quality in each paddock. The target carrying capacity of farmlets A and B were 15 and 7.5 DSE ha^{-1} respectively. In contrast, farmlet C employed intensive rotational grazing; this farmlet was subdivided into 16 and then 33 paddocks, allowing the movement of stock to be rotated between paddocks usually as 3 mobs, with short grazing intervals (commonly of 3-5 days) and long rest periods (80-200 days). The target carrying capacity for this system was 15 DSE ha^{-1}, the same as for farmlet A.

Over the first 5 years of the project, the mean stocking rates achieved on farmlets A, B and C were 13.4, 9.2 and 8.8 DSE ha^{-1} respectively.

While the high input system (farmlet A) consistently registered a higher percentage of sown fertiliser-responsive perennials than either of the moderate input systems (farmlets B and C), there was clear evidence that the proportion of the pastures represented by this species group declined across the three farmlets from 2000 to 2005. This decline was most strongly marked on farmlet B (from 28% to 5%) compared to farmlet A (from 76% to 41%) and farmlet C (from 44% to 18%). Conversely, while the percentage of native perennial grasses on farmlet A was consistently low (from 12 to 5%), these natives substantially increased from 49% to 62% on farmlet B and from 38% to 50% on farmlet C. The percentage of legumes and weeds remained low across the three farmlets during the study years, although some significant episodes of legume growth were observed on farmlet A during brief periods of favourable seasonal conditions.

The changes in pasture growth, herbage mass, and quality followed a seasonal pattern, generally with higher levels of these variables recorded over spring/summer and low levels in autumn/winter. While significant differences in pasture growth were not able to be detected at the level of measurement intensity employed over the generally drier than average years of the experiment, it was apparent that subtle differences did result in different levels of accumulation of herbage mass and quality leading to significant differences in livestock

production. Calibrated visual estimates of total and dead herbage mass were significantly higher on farmlets B and C compared to farmlet A. The green herbage mass on farmlet A was consistently higher than on the other farmlets, although the differences were not significant. It appears that the pasture growth rate on farmlet A was depressed somewhat due to the generally high level of pasture utilisation brought about the high stocking rate, resulting in relatively low levels of photosynthetically active leaves at many times.

Measurements of green herbage both before and after grazing demonstrated the rapid disappearance of green herbage, especially on farmlet C paddocks due to the high stock density. The rate of disappearance of green herbage on farmlet A was intermediate, due to its higher carrying capacity and higher pasture quality whilst the lowest rates of green herbage disappearance were on farmlet B paddocks.

Throughout most of the study period, pastures under a high input system (A) had significantly higher dry matter digestibility of dead herbage than pastures under either of the moderate input systems (B and C). In spite of this difference, over a two year period from autumn 2003 to autumn 2005, the digestibility of the dead herbage across all farmlets was lower than the level required to maintain animal condition. The digestibility of the green herbage was also significantly higher on farmlet A than on farmlets B and C. Crude protein levels in green herbage were also significantly higher on farmlet A compared to farmlets B and C.

Using the alkane technique within one paddock of each farmlet, sheep under both flexible grazing management systems (farmlets A and B) were found to be able to selectively graze particular pasture species more than under the intensive rotational grazing system (farmlet C). The estimated daily dry matter intake of weaners on farmlet A was found to be significantly higher than that of weaners grazing on farmlets B or C.

In 2003, the ewe liveweights and fat scores at joining, pre-lambing, and weaning were significantly higher on farmlets A and B than on C. Although in 2004 and 2005 the differences between the farmlets were not significant, there was a tendency for these values to be higher on farmlets A and B than on C. Ewes on farmlet A had significantly higher pregnancy rates, detected through scanning, and hence higher twinning rates than ewes on farmlets B and C in the years 2003 and 2005; however, there was no significant difference in 2004. Both the initial and final liveweights for wethers on farmlets A and B were significantly higher than those on farmlet C.

There was a significantly higher daily liveweight gain for steers and heifers both per head and

per hectare on farmlet A than on farmlets B and C. Also, sheep on the high input system produced significantly higher fleece cut per head and per hectare compared to those on moderate input systems. However, there was less difference between the farmlets in terms of fleece quality.

Measurements of animal production, both on a per head and per hectare basis, showed that the high input system (farmlet A) was more productive than the other farmlets. Animal production on the intensive rotational grazing farmlet (C) was found to be lower than that measured on the typical district grazing farmlet (B), thus demonstrating that some of the claims made for this system of grazing were not supported by the evidence.

The nutritional needs of all livestock were assessed using equations based on the Australian feeding standards for ruminant livestock. The significant increase in stocking rate, liveweight, growth rate, and reproductive rate of sheep on the high input system meant higher levels of metabolisable energy were required to satisfy the nutritional demand of these animals. The metabolisable energy supplied in pasture growth and through supplementation was generally inadequate to meet the demand calculated for the livestock, resulting in a generally negative partial balance between supply and demand across all farmlets. The fact that this balance was similar between farmlets supports the contention that the grazing 'pressure' applied to each farmlet was similar, in spite of the farmlets diverging in the number of livestock carried on each farmlet. At times, the extent of the negative partial balance on farmlet A was greater than on the other farmlets confirming that, at least at times, the stocking rate carried on this farmlet was probably too high, perhaps resulting in an accelerated rate of loss of valuable species and limiting the potential growth due to lower than desirable levels of green leaf capable of photosynthesising.

Matching the conflicting needs of pastures and animals was particularly challenging in this whole-farmlet experiment where complete capture of all necessary information across all paddocks and all animals was not feasible. Nevertheless, this situation is common in grazing enterprises where much less quantitative information is available. The needs of the broader Cicerone Project, determined by the Cicerone management team, influenced many of the decisions on stocking rate and stock movement thus posing some substantial challenges to the conduct of this research.

It is concluded that, with further development of more timely assessments of the balances between metabolisable energy supply and demand, paddock and grazing management could

be markedly improved, leading ultimately to more sustainable and profitable outcomes from grazing enterprises.

Acknowledgements

While pursuing my PhD was seemingly an endless job, the contributions, curiosities, and talents of many people, all of which worked towards its successful outcome, deserve to be acknowledged.

First and foremost, my special tribute goes to my principal supervisor Professor Jim Scott and my co-supervisor Dr. Geoff Hinch. Their foresight, enthusiasm, professional criticisms and never-ending open-door policy, provided excellent supervision right from conception to completion of this thesis. I have no words to express my deep gratitude to Professor Jim Scott. His initiative and assistance through continuous involvement in the research set up, field data collection and processing, laboratory analysis, statistical analysis, daily visits to my office and enabling the support from several database experts was invaluable.

The opportunity to undertake this research was provided by the Cicerone Project, which allowed access to the study site and the experimental animals. Funding for this research was provided by the University of New England with additional funds granted by Australian Wool Innovation and the National University of Lesotho in southern Africa. All this financial support is gratefully acknowledged.

I am indebted to Dr. Hugh Dove at CSIRO Plant Industry in Canberra, who developed the alkane technique, for his invaluable advice and clear explanations of how to use the technique for measuring intake and diet selection. I thank him also for providing free-of-charge the 'Eatwhat' software package used to compute many of the alkane results. I would like to express my special appreciation to Mr. Dan Alter and Ms Leanne Lisle for kindly purchasing all the required laboratory equipment and chemicals for the alkane analysis. I further thank Mr. Dan Alter for his skilled assistance in conducting the alkane extraction and chromatography. Additional information on how to use the alkane technique was provided by Dr. Chen Wen and Dr. Roger Hegarty – to whom I am very grateful.

My sincere thanks go to Mr Duncan Mackay, Dr. Paul Kristiansen, and Dr. Robert Murison for the high quality statistical advice and guidance they provided right from the commencement of this research to the final draft of my thesis. Particular recognition is due to Mr. Greg Chamberlain and Mr. Michael Raue for their invaluable field-technical assistance for two years. My candid appreciation goes to all technical staff in the Department of Agronomy and Soil Science for setting up the cages in the field to measure pasture growth, as well as for their assistance in sorting the pasture material into green and dead.

The complex database queries which needed to be constructed to assess the various pasture and animal data would not have materialised without the support of all the staff in the Relational Database Unit (Mr. Colin Lord, Mr. Dion Gallagher, Mr. Jim Cook and Mr. Ed Campbell). Some of the data used in this study were provided by the Farm Manager (Mr. Justin Hoad), the Executive Officer (Ms. Caroline Gaden), and the technical pasture consultant to the Cicerone Project (Mr. Colin Mulcahy). Not only did I enjoy doing field work with Mr. Colin Mulcahy, but I also gained a great deal of knowledge and skills from him regarding the identification of most of the pasture species in the Tablelands of NSW.

Professor Alfred Ebenebe, Dr. Keith Hutchinson, Dr. Kathy King, Dr. Graeme Blair, and Mr. Perminus Migwi, have generously given time, comments, and suggestions, which have led to me completing this thesis. My sincere gratitude goes to the Academic Skills Office (Ms. Julie Godwin) for professional guidance regarding scientific writing for a thesis. I also thank Mr. Craig Birchall for formatting assistance and Ms. Nicola Windeyer and Richard Willis for proof-reading my thesis chapters. The Office Administrator of the Department of Agronomy and Soil Science (Ms. Elizabeth Davies) provided immense assistance in all the administrative issues.

My thanks also go to the three anonymous external examiners for their critical and constructive comments which have guided me as I have worked to refine the thesis.

It is certain that I would never have ventured this far all alone without the unfailing love, support and encouragement of my dear husband, Elia, and our daughter, Mary-Stella Shakhane. I must say, Elia, that you have been my inspiration throughout my education career (from Diploma to PhD). Above all, I thank the merciful hand of the Almighty Lord that has seen me through this entire undertaking. *"My grace is sufficient for you, for my power is made perfect in weakness"* (2 Corinthians 12: 9).

Table of Contents

Chapter 1: Introduction **1**

High rainfall zone and the Northern Tablelands 1

History of pasture development on the Northern Tablelands 2

Issues related to sustaining pastures 2

Sustainable and profitable grazing enterprises 5

Research scale and complexity 6

The Cicerone Project 7

Chapter 2: Literature Review **11**

Introduction 11

Key pasture species groupings important to grazing enterprises 12

Sown perennial grasses *12*

Perennial legumes *14*

Native and naturalised pastures *14*

Key determinants of pasture production 17

Effect of climate and soil factors on pasture production *17*

Energy flow within the grassland ecosystem *20*

Grazing systems and pastures *24*

Impact of grazing management on pasture supply *25*

Effects of changes in soil fertility and pasture species on animal performance 36

Key determinants of animal production 38

Stocking rate and grazing management effects on animal performance *38*

Energy requirements of grazing livestock 43

The energy concentration of pasture and that required by grazing animals *43*

Matching animal requirements with seasonal pasture supply *44*

Sustainable grazing enterprises 46

Research scale and complexity 48

The Cicerone Project *50*

Concluding remarks 52

Chapter 3: General Materials and Methods **55**

The Cicerone Project farmlet experiment 55

The research layout 55

The study location and climate *55*

History of the site *58*

Farmlet management systems 60

Fertiliser application, pasture sowing and management *61*
Grazing strategies *62*
Pasture measurements and techniques used *66*
Animal management *66*
Supplementary feeding *67*
Statistical methodologies of selecting representative paddocks 69
Introduction *69*
Data sources *70*
Results and discussion *70*
Final selection of the representative paddocks 79
Chapter 4: Botanical composition 84
Experiment I: Whole farmlet and seasonal investigations of representative paddocks 84
Introduction *84*
Materials and methods *85*
Results *89*
Discussion *106*
Experiment II: Dietary selection of species 112
Introduction *112*
Materials and methods *113*
Results *117*
Discussion *122*
Chapter 5: Pasture supply 126
Introduction 126
Materials and methods 127
Measurements *127*
Data analysis *131*
Results 134
Whole-farmlet investigations *134*
Investigations on representative paddocks *138*
Discussion 145
Pasture growth rate *145*
Herbage mass *150*
Pasture quality *153*
Chapter 6: Animal Production 156
Introduction 156
Materials and methods 156

Animal handling and management *156*
Results 158
Reproductive ewes *158*
Discussion 170
Chapter 7: Process for Estimating the Balance between Pasture Supply and Animal Demand175
Introduction 175
Materials and methods 175
Measurements and ME calculations *175*
Results 178
Pasture supply *178*
Animal demand *179*
The net ME balance *181*
Discussion 183
Pasture supply *183*
Animal demand *183*
Partial net ME balance *183*
Chapter 8: General Discussion and Conclusions 186
Pasture supply *187*
Animal performance *190*
Balancing pasture supply and animal demand *193*
The development of more sustainable grazing enterprises 194
Research scale and complexity 195
References 197
Appendix 1. Pasture sowing and fertiliser records 212
Appendix 2. Statistical analyses of botanical composition data 214
Appendix 3. Alkane analysis 219
Appendix 4. Calibrations of monthly assessments of herbage mass, digestibility, green, clover and ground cover 231
Appendix 5. Pasture supply 234
Appendix 6. Animal performance 235

List of Figures

Figure 2.1 The relationship between stocking rate and weight gain per animal and per hectare according to (i) Hodgson (1990) for sheep and (ii) for animal units showing hypothetical curves representing a shift from continuous grazing in large paddocks to rotational grazing with increasing numbers of paddocks (Norton 1998).....39

Figure 2.2 Daily energy requirements to maintain (i) a 50kg pregnant ewe, allowing an additional 2MJ above maintenance for grazing, with a single foetus weighing 4kg at term, on high quality (M/D = 11) pasture (Source: (SCA 1990)) and (ii) potential ME output in milk of a single- and twin-bearing ewe during lactation Source: (Freer *et al.* 1997). 43

Figure 3.1 Actual and long-term average monthly rainfall from January 2000 to December 2005 for Armidale, NSW (Bureau of Meteorology).....56

Figure 3.2. Cumulative actual and long-term average monthly rainfall from January 2000 to December 2005 for Armidale, NSW (Bureau of Meteorology). 57

Figure 3.3. Actual and long-term average monthly maximum and minimum temperatures (^{o}C) from January 2000 to December 2005 for Armidale, NSW (Bureau of Meteorology). 57

Figure 3.4 The final paddock allocation across the three farmlets with A paddocks shown in pink, B paddocks presented in green and C paddocks indicated in blue. 59

Figure 3.5 Summary of comparisons between the farmlet systems. 60

Figure 3.6. Records of paddock moves expressed as the length of graze and rest periods for all mobs of sheep on all paddocks of farmlets A, B and C from July 2001 to December 2005. 65

Figure 3.7 The supplementation provided (kg/head/week) to different classes of stock from July 2000 to October 2005 on farmlets A, B and C. 69

Figure 3.8 Data for individual candidate paddocks and the means (±se) of the elevation (m a.s.l) for the paddocks of the three farmlets. 72

Figure 3.9 Principal component biplot relating the distances of the candidate paddocks of each of the three farmlets, A, B and C to the means of the two factors. 73

Figure 3.10 Data for individual candidate paddocks and the means (±se) of electromagnetic conductance (nm) for the three farmlets. 74

Figure 3.11 Two-dimensional plots of the factors, soil phosphorus and sulfur, from the principal component analysis of each of the three farmlets. 75

Figure 3.12 Means ±standard errors of (a) Colwell P and (b) KCl 40 S (mg kg-1) for individual candidate paddocks of each of the three farmlets. 76

Figure 3.13 Principal component biplot relating the distances of the candidate paddocks to the mean factors, sown grasses (SG) and native grasses (NG) on farmlets A, B and C. 77

Figure 3.14 Botanical composition (mean % se) of (a) sown and (b) native grasses for individual candidate paddocks from March 2000 to December 2002 on farmlets A, B and C. 78

Figure 3.15 Principal component biplot of the factors, soil electric conductivity (EC), pH and cation exchange capacity (CEC) on farmlets A, B and C. 79

Figure 4.1 Average botanical composition, expressed as aggregations of five species groupings, of all paddocks of farmlets A, B and C over five years from March 2000. 92

Figure 4.2. Botanical composition (%) of (a) sown fertiliser-responsive and (b) native warm-season perennial grasses in paddocks of farmlets A (paddocks 1-8), B (paddocks 1-8) and C (paddocks 1-16) over the years 2000 to 2005. 94

Figure 4.3 Percentage botanical composition of fertiliser-responsive and native warm-season perennial grasses for the three farmlets from 2000 to 2005. 95

Figure 4.4 The effect of management systems (A, B and C) on changes in the proportion of legumes (%) over a five-year period. 96

Figure 4.5 Changes in botanical composition of grass species groups from March 2000 to February 2005 in response to the effects of farmlet treatments (A, B and C). 97

Figure 4.6 The log odds of the grass species groups from March 2000 to February 2005. 99

Figure 4.7 The variation in botanical composition (%) of (a) fertiliser-responsive and (b) native perennial grasses for three paddocks of each farmlet over years 2000-2005. 105

Figure 4.8 Changes in the seasonal botanical composition (%) of nutrient-responsive perennial grasses in response to different input and grazing regimes over years 2000-2005. 106

Figure 4.9 Relationship between alkane carbon chain lengths (C_{25}- C_{36}) and their recoveries in faeces. 116

Figure 4.10 The diet composition (%) of the sheep grazing in paddocks A7, B1 and C1 in Summer (Feb), Autumn (Apr) and Spring (Oct) 2005 119

Figure 4.11 Botanical composition (%) of the pasture on offer and in the diet of sheep grazing in paddock A7, in summer, autumn and spring. 120

Figure 4.12 Botanical composition (%) of the pasture on offer and in the diet of sheep grazing in paddock B1, in summer, autumn and spring....121

Figure 4.13 Botanical composition (%) of the pasture on offer and in the diet of sheep grazing in paddock C1, in summer, autumn and spring....122

Figure 5.1 The fitted B-splines for the changes in total, green and dead herbage mass (kg DM ha^{-1} from the calibrated visually estimated data on all the paddocks of each farmlet from March 2003 to April 2005....135

Figure 5.2 The relationship between the monthly measurements of percent legume and green herbage mass (kg DM/ha) measured on all the paddocks of farmlets A, B and C. 136

Figure 5.3 The fitted B-splines for the changes in calibrated measurement of dry matter digestibility (% DM) from the 3 farmlet from March 2003 to April 2005. 137

Figure 5.4. The fitted B-splines for the changes in from calibrated measurement herbage crude protein (% DM) on 3 farmlet from May 2003 to March 2005....138

Figure 5.5 Average pasture growth rate (kg DM ha^{-1} day^{-1}) assessed from the changes in pre- and post-grazing herbage mass on farmlets A, B and C from July 2003 to April 2005. 139

Figure 5.6 The fitted Fourier curve representing net pasture growth rate (kg DM ha^{-1} day^{-1}) for three paddocks of each farmlet from June 2003 to February 2005....140

Figure 5.7 The changes in green herbage mass between pre- and post-grazing measurements for 3 representative paddocks within each of 3 farmlets over a two year period....141

Figure 5.8 The seasonal measurements of herbage mass and pasture growth rate on farmlets A, B and C from July 2003 to April 2005....142

Figure 5.9 The disappearance of herbage mass (green and dead) expressed in kg DM/DSE/week recorded during lambing (6th September to 25th October 2004)....143

Figure 5.10 The fitted B-splines for the legume herbage mass (kg DM/ha) on three representative paddocks of farmlets A, B and C from winter 2003 to autumn 2005....144

Figure 5.11 The changes in pasture quality (% DM Digestibility) during lambing/lactating period (06 September to 01 November 2004) in paddocks A2, B3 and C9....145

Figure 6.1 Fitted B-spline curves for the average ewe liveweight (kg $head^{-1}$) from November 2000 to November 2005 on farmlets A, B and C....159

Figure 6.2 Box whisker plots for the mean ewe liveweight at joining, pre-lambing and weaning from 2003-2005 on farmlets A, B and C. 160

Figure 6.3 Box whisker plots for the mean ewe fat score at joining, pre-lambing and weaning from 2003-2005 on farmlets A, B and C. 160

Figure 6.4 Fitted B-spline curves for the liveweight (kg head^{-1}) of weaner lambs born from spring 2000 to 2004 from marking (November each year) to 12 months later on farmlets A, B and C. 162

Figure 6.5 Relationship between ewe pregnancy rate and percent lambs marked, weaned or lost averaged across years and farmlets. The lines are the fitted quadratic functions..... 164

Figure 6.6 The initial and final liveweights (kg head^{-1}) of wethers on farmlets A, B and C measured in September 2003 and April 2005. 165

Figure 6.7 Sequential carrying capacity (dry sheep equivalent per hectare) for both sheep and cattle from July 2001 to November 2005 on farmlets A, B and C..... 167

Figure 6.8 Relationship between wool cut (both kg/head and kg/ha) and dry sheep equivalent (DSE/ha) on farmlets A, B and C. The symbols are the data points and the solid lines are the most fitted linear (a-c) and quadratic (d-f) functions fitted to the per head and per ha data, respectively 169

Figure 7.1 The effect of the farmlet treatments on estimated diet intake (kg DM/head/day) of the different classes of sheep over a two-year period from autumn 2003. 180

Figure 7.2 Estimated diet intake (kg DM/ha/day) of different classes of sheep on farmlets A, B and C over a two-year period from autumn, 2003. 180

Figure 7.3 Estimated partial metabolisable energy balance per hectare showing the changes in herbage on offer (a, b, c), pasture growth and supplement (d, e, f), animal demand (g, h, i) and net balance (pasture growth + supplement – demand) (j, k, l) on farmlets A, B and C. 182

Figure 2.1 Histogram, box and quantile plots for the eight species groups. The plots show the mean, standard error and the confidence intervals for the mean..... 215

Figure 3.1 Two-dimensional principal component plot showing the contribution of the alkane signatures of the pasture species to the first and second components at (a) first sampling (February 2005), (b) second sampling (April 2005) and (c) third sampling (October 2005). 225

Figure 3.2 Selection index expressed as the proportion of the component in the diet as a fraction the proportion of the same component on offer in paddocks A7, B1 and C1 in summer, autumn and spring 2005. 229

Figure 4.1. Example of data entry template (for February 9, 2005 sampling) showing data entry fields (purple) and calculated fields based on the calibration equations from estimates of herbage mass and digestibility (green and dead). 231

Figure 4.2. Example of typical calibration equation template for calculating estimates of total dry matter from visual estimates (for February 9, 2005 sampling) of herbage mass....232

Figure 4.3. Example of typical calibration equations (for February 9, 2005 sampling) from 5 samples of (a) green and (b) dead assessed both with a visual score (1-5) and measured for digestibility using NIRS. 232

Figure 6.1. Fitted B-spline curves for the average wether liveweight (kg head^{-1}) from marking (November 2001) to March 2004 on farmlets A, B and C. 235

Figure 6.2. Numbers of various classes of sheep and cattle run on Farmlets A, B and C from April 2003 to April 2005....236

List of Tables

Table 2.1 Minimum green pasture mass required for sheep (Source: Bell (2003)). 44

Table 3.1 Criteria used for characterising each of the paddocks within each farmlet. 70

Table 3.2 Ranking of the first three paddocks within each farmlet based on a range of criteria. 71

Table 3.3 Summary of the criteria used for making the final selection of a representative sample of 3 paddocks from each of farmlets A, B and C. 82

Table 4.1 Species were grouped according to their longevity, pattern of growth, nutritive value and drought resilience. 90

Table 4.2 The statistical significance of multivariate tests of the transformed data for the effects of farmlet, time and their interaction on species functional groups. 96

Table 4.3 The comparisons among the means of individual species which responded significantly to effect of the farmlet treatment over time. 102

Table 4.4. The Wilks' Lambda test showing Chi-square and significant levels of the variate functions one and two on species groups. 104

Table 5.1 Total herbage mass (kg DM ha^{-1} $year^{-1}$), averaged across all paddocks of the three farmlets over six years. 134

Table 6.1 Potential lambs per ewe based on twinning and pregnancy rates on farmlets A, B and C over years 2003-2005. 161

Table 6.2 The liveweight (kg $head^{-1}$ and kg ha^{-1}) of 2000-2004 weaner lambs at marking and at 12 months from marking on farmlets A, B and C. 163

Table 6.3 Ewe pregnancy rate (%) and the percentage of lambs marked and weaned per ewe joined on farmlets A, B and C. 164

Table 6.4 The initial and final liveweights (kg $head^{-1}$ and kg ha^{-1}) for the heifers and steers measured in October 2003 and May 2004 on three farmlets. 166

Table 6.5. The weight gain per head and per hectare of the heifers and steers between the three farmlets for a period of 12 months (from October 2003 to May 2004). 166

Table 6.6 Wool production from ewes (kg $head^{-1}$ and kg ha^{-1}) and annual stocking rate expressed as DSE ha^{-1} on farmlets A, B and C for the years 2002-2005. 168

Table 6.7 outlines the comparison of the traits of wool quality between the three farmlets over a period of 4 years. Farmlets A and B produced wool with significantly ($p<0.05$) higher micron than farmlet C in 2002-2003, but there were no significant differences in micron between the farmlets in years 2004-2005. 169

Table 6.8 Fibre diameter (μm), wool yield (%), staple length (mm) and staple strength (N/ktex) for ewes over years 2002-2005 on farmlets A, B and C.....170

Table 1.1 Summary of pasture treatments (fertilisers, sprays and sowing of pastures) applied to Farmlets A, B and C from 2000 to 2005.....212

Table 2.1 The estimated log odds of species groups for farmlets A and C relative to B over years 2000 to 2005 tested as deviance using the 'Wald test' (p>W).....216

Table 2.2 The univariate F-tests of individual species among the functional groups which responded significantly to the farmlet and time effects.....217

Table 2.3 Correlation coefficients between discriminating variables of individual species and standardised canonical discriminant functions.....218

Table 3.1 Preliminary analysis of *n*-alkane concentration (mg/kg DM) in *Trifolium repens* done in four repeats to set appropriate time to digest. 1hr heating, 2 extractions, and 3 washes (1A-1C); 1hr heating, 3 extractions, and 3 washes (2A-2C); 3hrs heating, 2 extractions, and 3 washes (3A-3C); 3hrs heating, 3 extractions, and 3 washes (4A-4C).....219

Table 3.2 Reported values for the recovery of naturally occurring n-alkanes in sheep faeces used to correct faecal alkane values prior to estimating diet composition. Source: (Lee 2000).....220

Table 3.3 Concentrations of ***n***-alkanes (mg/kg DM) in grasses, legumes and broadleaf weeds during 2005 summer (February), autumn (April) and spring (October) in one representative paddock of farmlet A (A7).....221

Table 3.4 Concentrations of ***n***-alkanes (mg/kg DM) in grasses, legumes and broadleaf weeds during 2005 Summer (February), Autumn (April) and Spring (October) in one representative paddock of farmlet B (B1).....222

Table 3.5 Concentrations of *n*-alkanes (μg/g DM) in grasses, legumes and broadleaf weeds during 2005 summer (February), autumn (April) and spring (October) in one representative paddock of farmlet C (C1).....223

Table 3.6 The variance in the pattern of odd-numbered alkanes explained by the first three principal components.....226

Table 3.7 Mean values of the first three principal components in pasture species at first sampling (Summer 2005. In brackets are the species codes used in Figure 3.1 227

Table 3.8 Mean values for the first three principal components in pasture species at second sampling (Autumn 2005 In brackets are the species codes used in Figure 3.1.....228

Table 3.9 Mean values for the first three principal components in pasture species at third sampling (Spring 2005). In brackets are the species codes used in Figure 3.1.....229

Table 4.1. Summary of R^2 values for linear and quadratic fitting of equations to calibration data for monthly assessments of herbage mass and digestibility (green and dead).....233

Table 5.1 Analysis of variance showing the F-value tests and probability differences for the factors with their interaction effects on pasture growth rate.....234

Table 5.2 The average means of total, green and dead herbage (kg DM ha-1 on farmlets A, B and C over two years (visually estimated data from all the paddocks).....234

Table 6.1 The mean liveweight (kg $head^{-1}$) and fat score for the ewes on three farmlets from 2003-2005.....235

Table 6.2 Pregnancy scan (%) for empty, single and twin bearing ewes during their pregnancy in years 2003-2005 on farmlets A, B and C.....235