

**Predicting native pasture growth in the Victoria River
District of the Northern Territory**

A thesis submitted by

Michael D. Cobiac

B. App. Sc. (Ag.)

to the

School of Agriculture, Food and Wine

Faculty of Sciences

The University of Adelaide, Australia

as fulfilment of the requirements of

Doctor of Philosophy

December 2006

Declaration of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being made available in all forms of media, now or hereafter known.

Signed:

Michael Cobiac

Date:

Acknowledgments

The successful completion of this study has involved considerable assistance from many people throughout the planning, research, analysis, and reporting phases. The efforts of the following people are gratefully acknowledged.

Funding: The fieldwork and GRASP model calibration reported in this study were funded by Meat and Livestock Australia's (MLA's) North Australia Program. In addition, MLA's provision of a Junior Research Fellowship allowed me to concentrate full time on finalising this thesis. Their contribution has been central to the completion of this work.

My principal supervisor Dr Bill Bellotti (The University of Adelaide) for encouraging me down the post-graduate path, always being available for advice when needed during the preparation of this thesis, and his quiet insistence that I produced work of a high standard. The role of supervisor is crucial to a student's candidature, and I have been very fortunate having Bill's guidance throughout my study.

My co-supervisor Ken Day (Qld Dept. of Natural Resources and Mines) for a great many things. He provided advice on field data collection, collaborated with me during calibration of the GRASP model, and reviewed my work many times. Mostly, however, I thank Ken for his undying faith, patience and friendship throughout the course of this study. This work would never have been completed without his commitment, and for that I am indebted.

Dr Greg McKeon (Qld Dept. of Natural Resources and Mines) for his repeated efforts to educate me about the GRASP model, his endless enthusiasm for the quest to improve landscape use by the northern Australian pastoral industry, and leading me to think in ways I never knew were possible. It has been a privilege to work with a scientist of his calibre.

Former NT Dept. of Primary Industry and Fisheries (now DPIFM) staff: Tom Stockwell for the job; Rodd Dyer for being a great friend and demonstrating work ethic like I'd never seen before; and Anne Lyon, Bruno Hogan, Linda Cafe and the staff of Victoria River Research Station (Kidman Springs) for being good mates and for assistance with collection of data in the field, sometimes under very difficult conditions.

Neil MacDonald, Robyn Cowley, Trudi Oxley, Kieren McCosker, Annemarie Huey and Caz Smith who are the current generation of bright minds at Katherine Research Station furthering our understanding of sustainable pastoralism in the semi-arid tropics of the NT. It is a great motivating factor to know the outcomes of this work will (indeed already do) play a significant role in ongoing pastoral research.

The NT Cattleman's Association and the producers of the Victoria River District for allowing me to conduct field research on their properties, for access to confidential property data, and for their hospitality and open-minded discussions over many years. This thesis is ultimately for them, the people who manage the landscape.

Shafiq, Ali, Eun-Young, Yasmine, Bagarath, Juan, Vahid and Bandara: the international postgraduate students at The University of Adelaide's School of Agriculture, Food and Wine for befriending me, broadening my mind, and who present their theses in English - to them a second language. As challenging as things got sometimes, nothing in my study was as hard as that.

The many other people with whom I interacted during this study and who provided encouragement when the path forward seemed long, arduous and unclear.

Most importantly, I thank Cath for putting up with my long absences, understanding my need to see this study through to completion, and supporting me when it was needed most. Her faith in me carried me through many moments of doubt.

Abstract

Pastoralism is the major economic activity in the Victoria River District (VRD), and is dependent on sustainable pasture use. Analysing grazing practices for sustainability requires knowledge of annual pasture production, but little quantitative data is available. A study was undertaken to develop the capacity for predicting native pasture growth in the VRD using systems modelling. Twenty one field sites were studied for two years using a standard methodology, and the Grass Production (GRASP) model was calibrated using this field data. End of growing season total standing dry matter (TSDM) was well predicted (mean = 2513kg/ha, $r^2(1:1) = 0.966$, RMSE = 132kg/ha, and 98% of predictions within measurement variance).

Developing generic parameters for common soil and pasture types allowed extrapolation of the model. Predictive skill declined when using generic parameters ($r^2(1:1) = -0.265$, RMSE = 807kg/ha and 64% of predictions within measurement variance). However, observation and prediction means were very similar, indicating that generic parameters are suitable for broad scale applications, but site-specific parameters are necessary if a high degree of accuracy is required. Parameters controlling plant water uptake largely determine pasture growth in low rainfall years, while nitrogen uptake and dilution parameters limit growth in high rainfall years. Pasture growth is constrained by nitrogen supply in 91% of seasons in the northern VRD, and in 25% of seasons in the drier south.

Example applications of the model were demonstrated. Current and expected future levels of pasture utilisation in the district were calculated, showing a current average of 16%, rising to an expected 20% in the next decade. These levels are within the safe utilisation rates recommended for the region. Economic analysis shows positive returns (\$4.54 million per year) from pasture augmentation with introduced legumes if past problems with establishment and persistence can be overcome.

Model performance would be improved by accounting for simultaneous wetting of the entire profile in cracking clay soils, calculating growth of perennial and annual pasture species separately, and simulating variation in nitrogen uptake and dilution between years. Incorporation of these processes must be balanced against the increased complexity of the model and the additional data required for calibration.

Table of Contents

Declaration of Originality	ii
Acknowledgments	iii
Abstract.....	v
Table of Contents	vi
List of Figures.....	viii
List of Tables	xiv
List of Plates	xviii
1.0 Introduction.....	1
2.0 Review of literature.....	5
2.1 A brief description of the Victoria River District	5
2.2 The pastoral industry.....	9
2.3 Current understanding of factors influencing pasture growth.....	11
2.4 A modelling approach to assessing pasture growth	20
2.5 Testing the performance of a systems model.....	28
2.6 The role of systems modelling in grazing land management.....	33
2.7 Conclusions.....	34
2.8 Outline of the study ahead	34
3.0 A field study of native pasture growth in the VRD.....	36
3.1 Introduction.....	36
3.2 Rationale for obtaining data to calibrate the GRASP pasture growth model.....	37
3.3 Methods of data collection	38
3.4 Field results.....	50
3.5 Discussion of field study results	105
3.6 Conclusions.....	117
4.0 Analysis of field measurements using a systems modelling approach	119
4.1 Introduction.....	119
4.2 An overview of the GRASP pasture growth model	121
4.3 Method for deriving model parameters and calibrating GRASP	127
4.4 Results of calibration: Final model parameters.....	133
4.5 Comparing model outputs with field data.....	143
4.6 Discussion of the calibration procedure and modelling results.....	156
4.7 Conclusions.....	169
5.0 Testing the performance of GRASP for application to the wider landscape ...	170
5.1 Introduction.....	170

5.2	Generic parameters suitable for extrapolation across the landscape	171
5.3	Testing model performance using independent data	177
5.4	Discussion of independent validation of GRASP.....	186
5.5	Conclusions	189
6.0	Determining parameters most influential on predictions of long-term pasture growth	190
6.1	Introduction	190
6.2	Modelling year-to-year variability in pasture growth across a climate gradient	191
6.3	Sensitivity of model predictions to changes in value of influential parameters	200
6.4	The effect of trees on predictions of pasture growth	205
6.5	Discussion.....	208
6.6	Conclusions	213
7.0	Implications for analysing grazing practices in the VRD: examples of model application	214
7.1	Introduction	214
7.2	Pasture utilisation in the VRD	215
7.3	Potential benefits of alleviating the nitrogen limitation to pasture growth.....	228
7.4	Discussion.....	241
7.5	Conclusions	248
8.0	Integrating discussion and final conclusions of study	249
8.1	Introduction	249
8.2	The capacity to predict pasture growth in the VRD	249
8.3	Limitations of the systems modelling approach used in this study	252
8.4	Recommendations for future work	256
8.5	Final conclusion.....	257
	Appendices.....	258
	References.....	311

List of Figures

Chapter 1

- Figure 1.1** The location of the Victoria River District of the Northern Territory. 2
- Figure 1.2** Illustration of the structure of this thesis. 4

Chapter 2

- Figure 2.1** Seasonal rainfall (July to June, mm) at Victoria River Downs Station for the period 1900/01 to 2003/04. The horizontal dashed line represents the median value (639mm) (Source: DataDrill 2005). 6
- Figure 2.2** Land tenure in the Victoria River District in 2004 (data sourced from NT Dept of Lands). 8
- Figure 2.3** Total cattle population and annual turnoff (number of animals sold) for the Victoria River District 1883 – 2004 (S. Murti *pers.comm.*, based on Australian Bureau of Statistics and NT Office of Resource Development data). Dashed lines represent interpolation across periods where no data is available. Early data has been left as isolated points as no basis for interpolation is available. 10
- Figure 2.4** Annual trends in *LI*, *TI*, *MI* and *GI* values at Katherine, NT for: **a**) tropical grasses, and **b**) tropical legumes; **c**) the relationship between mean daily temperature ($^{\circ}\text{F}$) and fractional dry matter production in three groups of pastures (Fitzpatrick and Nix 1970). 23
- Figure 2.5** **a**) Thermal response curves of tropical grasses and legumes including the solid line used in the study of McCown (1981a); **b**) moisture index function of McCown *et al.* (1974). 25
- Figure 2.6** Structure of the water balance model and pasture sub-model in GRASP (Littleboy and McKeon 1997). 27
- Figure 2.7** Examples of GRASP model output for individual seasons, and over 15 years from Johnston (1996). 28
- Figure 2.8** Examples of two approaches to model testing from Mitchell and Sheehy (1997). 32

Chapter 3

- Figure 3.1** The structure of Chapter 3. 37
- Figure 3.2** The five main locations of the study sites within the Victoria River District (shaded area). Dashed lines represent approximate average annual rainfall isohyets (Source: adapted from BoM data). 40
- Figure 3.3** Design and layout of study site showing cells (dashed line squares) and an example pattern of quadrat placement (solid line squares) for each pasture measurement (H1 to H8). Quadrat location for each pasture measurement was randomised for each site. 42
- Figure 3.4** Time-series of management and data collection from each site over the study period. 51
- Figure 3.5** Maximum and minimum daily temperatures ($^{\circ}\text{C}$) at Mt Sanford ($17^{\circ}12'\text{S}$, $130^{\circ}36'\text{E}$) over the study period (upper graph) compared to the 7-day moving averages of 47-year values (1957/58 – 2003/04);

and measured daily rainfall averaged across Sites 1-6 (lower graph). Temperature data derived from DataDrill (2005).....	54
Figure 3.6 Total monthly measured rainfall at Mt Sanford averaged across Sites 1-6, and 47-year median values (1957/58 – 2003/04) derived from DataDrill (2005).	54
Figure 3.7 Maximum and minimum daily temperatures (⁰ C) at Kidman Springs (16 ⁰ 06'S, 131 ⁰ 00'E) over the study period (upper graph) compared to the 7-day moving averages of 47-year values (1957/58 – 2003/04); and measured daily rainfall averaged across Sites 7-12 for 1993/94, Sites 7-14 for 1994/95 and Sites 13-14 for 1995/96 (lower graph). Temperature data derived from DataDrill (2005).....	55
Figure 3.8 Total monthly measured rainfall at Kidman Springs averaged across Sites 7-12 for 1993/94, Sites 7-14 for 1994/95 and Sites 13-14 for 1995/96, and 47-year median values (1957/58 – 2003/04) derived from DataDrill (2005).....	55
Figure 3.9 Maximum and minimum daily temperatures (⁰ C) at Victoria River Downs (16 ⁰ 24'S, 131 ⁰ 06'E) over the study period (upper graph) compared to the 7-day moving averages of 47-year values (1957/58 – 2003/04); and measured daily rainfall at the station homestead (lower graph). Temperature data derived from DataDrill (2005).....	56
Figure 3.10 Total monthly measured rainfall at Victoria River Downs homestead, and 47-year median values (1957/58 – 2003/04) derived from DataDrill (2005).	56
Figure 3.11 Maximum and minimum daily temperatures (⁰ C) at Rosewood (16 ⁰ 30'S, 129 ⁰ 00'E) over the study period (upper graph) compared to the 7-day moving averages of 47-year values (1957/58 – 2003/04); and measured daily rainfall at the station homestead (lower graph). Temperature data derived from DataDrill (2005).....	57
Figure 3.12 Total monthly measured rainfall at Rosewood homestead, and 47-year median values (1957/58 – 2003/04) derived from DataDrill (2005).....	57
Figure 3.13 Maximum and minimum daily temperatures (⁰ C) at Auvergne (15 ⁰ 24'S, 130 ⁰ 00'E) over the study period (upper graph) compared to the 7-day moving averages of 47-year values (1957/58 – 2003/04); and measured daily rainfall at the station homestead (lower graph). Temperature data derived from DataDrill (2005).....	58
Figure 3.14 Total monthly measured rainfall at Auvergne homestead, and 47-year median values (1957/58 – 2003/04) derived from DataDrill (2005).....	58
Figure 3.15 Field-measured soil water contents of sites located on red earths overlying basalt.....	63
Figure 3.16 Field-measured soil water contents of sites located on red earth overlying limestone.	65
Figure 3.17 Field-measured soil water contents of sites located on cracking clays overlying basalt.....	67
Figure 3.18 Field-measured soil water contents of sites located on cracking clays of alluvial origin.	71
Figure 3.19 The observed phases of plant growth during the study period for: a) the annual short grass <i>Brachyachne convergens</i> ; b) the annual mid-height grass <i>Iseilema vaginiflorum</i> ; c) the perennial tussock grass <i>Astrebla pectinata</i> ; and d) the perennial tuft grass <i>Chrysopogon fallax</i>	80
Figure 3.20 Pasture composition of three sites dominated by barley Mitchell grass. Error bars indicate the standard error of the site mean for total standing dry matter at each sampling time (harvest).	82

Figure 3.21 Pasture nitrogen contents (dashed lines) and nitrogen uptake (vertical bars) of three sites dominated by barley Mitchell grass.....	83
Figure 3.22 Plots of total standing dry matter (TSDM) against: a) total plant cover; and b) plant height for sites dominated by barley Mitchell grass.....	84
Figure 3.23 Pasture composition of three sites dominated by ribbon grass. Error bars indicate the standard error of the site mean for total standing dry matter at each sampling time (harvest).....	87
Figure 3.24 Pasture nitrogen contents (dashed lines) and nitrogen uptake (vertical bars) of three sites dominated by ribbon grass.....	88
Figure 3.25 Plots of total standing dry matter (TSDM) against: a) total plant cover; and b) plant height for sites dominated by ribbon grass.....	90
Figure 3.26 Pasture composition of three sites dominated by other perennial grass species. Error bars indicate the standard error of the site mean for total standing dry matter at each sampling time (harvest).....	92
Figure 3.27 Pasture nitrogen contents (dashed lines) and nitrogen uptake (vertical bars) of three sites dominated by other perennial grass species.....	93
Figure 3.28 Plots of total standing dry matter (TSDM) against: a) total plant cover; and b) plant height for sites dominated by other perennial grass species.....	95
Figure 3.29 Pasture composition of sites dominated by annual short grass species. Error bars indicate the standard error of the site mean for total standing dry matter at each sampling time (harvest).....	97
Figure 3.30 Pasture nitrogen contents (dashed lines) and nitrogen uptake (vertical bars) of sites dominated by annual short grass species.....	98
Figure 3.31 Plots of total standing dry matter (TSDM) against: a) total plant cover; and b) plant height for sites dominated by annual short grass species.....	99
Figure 3.32 Pasture composition of sites dominated by forb species. Error bars indicate the standard error of the site mean for total standing dry matter at each sampling time (harvest).....	102
Figure 3.33 Pasture nitrogen contents (dashed lines) and nitrogen uptake (vertical bars) of sites dominated by forb species.....	103
Figure 3.34 Plots of total standing dry matter (TSDM) against: a) total plant cover; and b) plant height for sites dominated by forb species.....	104
Figure 3.35 Relationships between perennial grass basal area (PGBA) and end of growing season standing dry matter (SDM) of a) perennial grasses; b) annual grasses and forbs; and c) total pasture.....	115

Chapter 4

Figure 4.1 The structure of Chapter 4.....	120
Figure 4.2 The four phases of systems analysis (bolded text in box) and an indication of where the components of this study fit within this framework (after Grant <i>et al.</i> 1997).....	120
Figure 4.3 Relationship between accumulated pasture transpiration and nitrogen uptake (from Littleboy and McKeon 1997). The user-defined coefficients for stored plant N reserves, N uptake per 100mm of	

transpiration, and maximum N available for uptake shown in this figure are realistic for the semi-arid tropics, but are examples only.	124
Figure 4.4 Flow of dry matter through the biomass pools (bolded) in the pasture system (modified from Littleboy and McKeon 1997). Processes that transfer dry matter from one biomass pool to another are presented in italics.	125
Figure 4.5 Typical daily biomass accumulation curve for native pasture in the Victoria River District, including approximate times of field measurements and the parameters in GRASP that are calibrated from data collected at these times.	133
Figure 4.6 Examples of time-series plots of prediction curves (lines) with observed values (points, including 95% confidence limits in the TSDM plots). Data presented are from sites of different soil type and pasture species composition: Site 4 (forbs on basalt clay); Site 8 (ribbon grass on alluvial clay); Site 1 (annual short grasses on basalt red earth); Site 14 (other perennial grasses on limestone red earth); Site 5 (barley Mitchell grass on basalt clay); Site 12 (other perennial grasses on limestone red earth); Site 3 (barley Mitchell grass on basalt clay); and Site 15 (forbs on alluvial clay).	148
Figure 4.7 Observed vs. predicted data for all sites. Model predictions are the results of using individual site parameter sets. Variables presented are total standing dry matter (TSDM), nitrogen uptake (N uptake), plant available water content in the 0-50cm layer of the soil (PAWC), and green plant cover. Associated statistics are presented in Table 4.7.	151
Figure 4.8 Deviation of predictions (points) from observed values (line of zero deviation) of total standing dry matter for all sites and years. Predictions are generated by GRASP using the individual parameter sets presented in Table 4.1 to Table 4.6. Dashed lines indicate the envelope of acceptable precision, equal to the average magnitude of measurement variance ($\pm 35\%$ of observation values).	155
Figure 4.9 Deviation of prediction values (points) from their corresponding observations of TSDM (x on line of zero deviation and including 95% confidence limits) for Site 4 and Site 8.	155
Figure 4.10 Deviation of predictions (points) from observed values of total standing dry matter (x on line of zero deviation and including 95% confidence limits) for all observations less than 500kg/ha.	164

Chapter 5

Figure 5.1 The structure of Chapter 5.	171
Figure 5.2 Illustration of the procedure for assembling data for the independent validation of GRASP, using the annual short grasses group as an example. S01Y1 refers to Site 1, Year 1; S01Y2 refers to Site 1, Year 2; and so on.	180
Figure 5.3 Observed vs. predicted TSDM for independent model validation using four approaches to developing generic parameter sets.	183
Figure 5.4 Deviation of predictions (points) from observed values (line of zero deviation) of total standing dry matter (TSDM) during independent validation. Predictions are generated by GRASP using four approaches to developing generic group parameter sets (Table 5.2). Dashed lines indicate the envelope of	

acceptable precision, equal to the average magnitude of measurement variance ($\pm 35\%$ of observation values).
..... 184

Chapter 6

Figure 6.1 The structure of Chapter 6.....	191
Figure 6.2 Time-series of simulated seasonal pasture growth (SSPG, July to June) over a 45-year period (1959/60 to 2003/04) using the <i>Regional VRD</i> parameter set at three locations in the VRD.	198
Figure 6.3 Probability distribution of simulated seasonal pasture growth (SSPG, July to June) over a 45-year period (1959/60 to 2003/04) using the <i>Regional VRD</i> parameter set at three locations in the VRD. The horizontal dashed line represents the median (50 th percentile) value.....	198
Figure 6.4 Probability distributions of simulated seasonal pasture growth (SSPG, July to June) over a 45-year period (1959/60 to 2003/04) using a) five <i>Species</i> group parameter sets; and b) three <i>Soil</i> group parameter sets at Victoria River Downs. Horizontal dashed lines represents median (50 th percentile) values.	198
Figure 6.4	199
Figure 6.5 a) Time-series of seasonal rainfall (July to June); and b) relationship between seasonal rainfall and simulated seasonal pasture growth (SSPG) over a 45-year period (1959/60 to 2003/04) using <i>Regional VRD</i> parameters at three locations in the VRD. The plotted regression is for seasons when SSPG was less than the upper limit of 3345kg/ha.....	199
Figure 6.6 a) Time-series of cumulative seasonal transpiration (July to June); and b) relationship between seasonal transpiration and simulated seasonal pasture growth (SSPG) over a 45-year period (1959/60 to 2003/04) using <i>Regional VRD</i> parameters at three locations in the VRD. The plotted regression is for seasons when SSPG was less than the upper limit of 3345kg/ha.....	199
Figure 6.7 a) Time-series of nitrogen uptake (July to June); and b) relationship between N uptake and simulated seasonal pasture growth (SSPG) over a 45-year period (1959/60 to 2003/04) using <i>Regional VRD</i> parameters at three locations in the VRD. The plotted regression is for seasons when N uptake was less than the upper limit of 24kg/ha/year.....	199
Figure 6.8 Sensitivity of simulated seasonal pasture growth results (SSPG) using a standard parameter set at Victoria River Downs to changes in values of transpiration-use-efficiency, green yield at 50% green cover, and soil water index at which growth stops. The horizontal dashed lines represent the median (50 th percentile) value.	203
Figure 6.9 Sensitivity of simulated seasonal pasture growth (SSPG) using a standard parameter set at Victoria River Downs to changes in values of maximum N uptake, N content at which growth stops, and N uptake per 100mm of transpiration. The horizontal dashed lines represent the median (50 th percentile) value.	204
Figure 6.10 Time-series of simulated seasonal pasture growth (SSPG, July to June) in the absence and the presence of trees over 45 years (1959/60 to 2003/04) at a) Auvergne (mean annual rainfall = 900mm); and b)	

Inverway (mean annual rainfall = 577mm). Tree basal area (TBA) was set at 6.0m²/ha at Auvergne and 2.0m²/ha at Inverway. 207

Figure 6.11 Probability distribution of simulated seasonal pasture growth (SSPG) in the absence and the presence of trees over 45 years (1959/60 to 2003/04) at two locations in the VRD. 207

Figure 6.12 Presentation yield of tallgrass pasture at the end of growing season in lightly grazed native pasture woodlands at Manbulloo, near Katherine NT (McIvor *et al.* 1994) and GRASP predictions of seasonal pasture growth (July to June) using *Regional VRD* parameters and tree basal area of 7.0m²/ha. 207

Chapter 7

Figure 7.1 The structure of Chapter 7. 214

Figure 7.2 Relationship between intake at long-term stocking rate and median simulated seasonal pasture growth (SSPG) across 10 properties in the VRD using stocking rate data provided in the 1997 survey (Smith 1998) and pasture growth predicted using the *Soil x Species* approach to developing generic parameters. The dashed line represents a similar relationship from three regions in Queensland (Hall *et al.* 1998). 223

Figure 7.3 Effect of climate variability on annual pasture utilisation over a 45 year period (1959/60 to 2003/2004) when a constant stocking rate is maintained (district average = 9.2AE/km², Table 7.4). 227

Figure 7.4 Effect of climate variability on annual stocking rate over a 45 year period (1959/60 to 2003/2004) when a constant utilisation rate is maintained (district average = 16.3%, Table 7.4). 227

Figure 7.5 a) Time-series; and **b)** probability distribution of simulated seasonal pasture growth (SSPG) in the absence of trees over 45-year period (1959/60 to 2003/04) using *Regional VRD* parameters at Auvergne when maximum nitrogen supply (MaxN) is limited (24kg/ha, the observed district average) and theoretically unlimited (96kg/ha). 233

Figure 7.6 Relationship between simulated seasonal pasture growth (SSPG, July to June) and **a)** seasonal transpiration (July to June); and **b)** total nitrogen uptake in the absence of trees over 45 years (1959/60 to 2003/04) at Auvergne when maximum nitrogen supply (MaxN) is limited (24kg/ha, the observed district average) and theoretically unlimited (96kg/ha). 234

Appendices

Figure 9.1 Pasture composition results not presented in Chapter 3. Error bars indicate the standard error of the site mean for total standing dry matter at each sampling time (harvest). (Figure continued overleaf) 280

Figure 9.2 Pasture nitrogen contents (dashed lines) and nitrogen uptake (vertical bars) of sites not presented in Chapter 3. (Figure continued overleaf) 282

List of Tables

Chapter 2

Table 2.1 Climate data at Victoria River Downs Station for the period 1900/01 to 2003/04 (source: DataDrill 2005).....	6
Table 2.2 Summary of existing pasture production data for the VRD.	19

Chapter 3

Table 3.1 Matrix of land systems by parent material and soil type (adapted from Stewart <i>et al.</i> 1970).	39
Table 3.2 General description of the 21 study sites at 5 locations in the Victoria River District (VRD).....	44
Table 3.3 Measured seasonal rainfall (July - June) over the study period, the 47-year (1957/58 – 2003/04) median value, and rainfall percentiles. Median data calculated from DataDrill (2005).	53
Table 3.4 Monthly values for radiation, evaporation and vapour pressure deficit at Victoria River Downs during the study period (source: DataDrill 2005).	60
Table 3.5 Soil description for sites located on red earths overlying basalt.	62
Table 3.6 Physical properties of soils at sites located on red earths overlying basalt.	62
Table 3.7 Soil description for sites located on red earths overlying limestone.	64
Table 3.8 Physical properties of soils at sites located on red earths overlying limestone.	64
Table 3.9 Soil description for sites located on cracking clays overlying basalt.	66
Table 3.10 Physical properties of soils at sites located on cracking clays overlying basalt.	67
Table 3.11 Soil description for sites located on cracking clays of alluvial origin.....	69
Table 3.12 Physical properties of soils at sites located on cracking clays of alluvial origin.....	70
Table 3.13 Example to demonstrate extrapolating soil moisture values to missing data points.	73
Table 3.14 Estimated dates of initiation of pasture growth for each study location, based on criteria of receiving both 50mm of rain within 14 days and 75mm within 28 days of the initiation date.	77
Table 3.15 Main pasture and tree species present during the study period for sites dominated by barley Mitchell grass (<i>Astrebla pectinata</i>).....	81
Table 3.16 Results for N and P status of pasture at sites dominated by barley Mitchell grass.	84
Table 3.17 Some important pasture variables at sites dominated by barley Mitchell grass.	84
Table 3.18 Main pasture and tree species present during the study period for sites dominated by ribbon grass (<i>Chrysopogon fallax</i>).	86
Table 3.19 Results for N and P status of pasture at sites dominated by ribbon grass.	89
Table 3.20 Some important pasture variables at sites dominated by ribbon grass.	89

Table 3.21 Main pasture and tree species present during the study period for sites dominated by other perennial grass species.....	91
Table 3.22 Results for N and P status of pasture at sites dominated by other perennial grass species.....	94
Table 3.23 Some important pasture variables at sites dominated by other perennial grass species.	94
Table 3.24 Main pasture and tree species present during the study period for sites dominated by annual short grass species.....	96
Table 3.25 Results for N and P status of pasture at sites dominated by annual short grass species.	99
Table 3.26 Some important pasture variables at sites dominated by annual short grass species.....	99
Table 3.27 Main pasture and tree species present during the study period for sites dominated by forb species.	101
Table 3.28 Results for N and P status of pasture at sites dominated by forb species.	104
Table 3.29 Some important pasture variables at sites dominated by forb species.....	104
Table 3.30 Variability in rainfall at the five study locations in the VRD. Rainfall data from DataDrill (2005).	106
Table 3.31 Summary of results for important soil variables.	109
Table 3.32 Summary of soil chemistry results for each of the major soil types in this study.	110
Table 3.33 Summary of field results for important pasture variables.	112
Table 3.34 Variance in field measurements of total standing dry matter (TSDM) for 21 sites over two years. Values represent 95% confidence limits expressed as a proportion of the harvest mean.	113

Chapter 4

Table 4.1 Site-by-year calibrated GRASP soil parameters. (Table continued overleaf).....	135
Table 4.2 Site-by-year calibrated GRASP sward structure parameters. (Table continued below).....	138
Table 4.3 Site-by-year calibrated GRASP plant growth parameters. (Table continued below).....	139
Table 4.4 Site-by-year calibrated GRASP nitrogen parameters. (Table continued below).....	140
Table 4.5 Tree parameters for Site 19.	141
Table 4.6 Site-by-year calibrated GRASP detachment parameters. (Table continued below).....	142
Table 4.7 Results of statistical comparison of predictions and observed values for all sites, using individual site parameter sets. Data presented is total standing dry matter (TSDM), plant available water content of the 0-50cm layer of the soil (PAWC), nitrogen uptake (N uptake), and green plant cover (Cover).....	153
Table 4.8 Summary of the number of predictions of TSDM that fell outside the envelopes of acceptable precision.....	156
Table 4.9 Summary of parameter values derived during calibration of GRASP to the study sites.	158
Table 4.10 Summary of model calibration results for total standing dry matter.	162

Chapter 5

Table 5.1 Matrix of study sites (numbers in table) as they relate to soil and species groups for development of generic parameter sets.	172
Table 5.2 Generic parameter values for <i>Soil</i> , <i>Species</i> , and <i>Regional VRD</i> groups. (Table continued overleaf)	175
Table 5.3 Source of parameters used to calculate partial estimates for independent model validation. This table is based upon the matrix presented in Table 5.1.	181
Table 5.4 Results of comparing model predictions with observed values of TSDM for independent validation using four approaches to developing generic parameter sets.	185
Table 5.5 Summary of predictions of TSDM that fell outside the envelopes of acceptable precision (95% confidence limits of the corresponding observation) using four approaches to developing generic parameter sets.	185
Table 5.6 Summary of results of independent validation of GRASP (including comparative results from calibration in Chapter 4) for end of wet season total standing dry matter.	188

Chapter 6

Table 6.1 Summary of year-to-year variation in predictions of pasture growth over 45 years at three locations in the VRD.	209
---	-----

Chapter 7

Table 7.1 Some estimates of long-term safe levels of pasture utilisation across northern Australia.	216
Table 7.2 Stocking rate and burning frequency for each land system in the 1997 survey; and estimations of tree basal area, closest associated generic pasture and soil parameters, and estimated soil depth for each land system.	221
Table 7.3 Median simulated seasonal pasture growth (SSPG) calculated using the <i>Site x Species</i> approach to developing generic parameters; and long term utilisation rates for specific land systems on 10 properties in the VRD, using stocking rate data provided in the 1997 survey (Smith 1998).	224
Table 7.4 Current and expected future stocking rates (SR) and levels of pasture utilisation (Util) on 22 properties in the VRD using property carrying capacity and grazing area data from the 2004 survey (Oxley 2006). Pasture growth used to determine utilisation calculated from the <i>Regional VRD</i> parameter set at Victoria River Downs.	226
Table 7.5 Comparison of simulated key nitrogen and pasture variables under nitrogen-limited and unlimited conditions, and in the presence and absence of trees at Auvergne over a 45 year period (1959/60 to 2003/04). Values across each row are not necessarily from the same season.	234
Table 7.6 Year-to-year costs of augmenting native pasture with legumes in the northern Ord-Victoria Area (adapted from Oxley and Walker (2003). Pastures require renovation and re-establishment after 10 years. All values are \$/ha.	238

Table 7.7 Projected benefit of augmenting native pastures with legumes in the northern Ord-Victoria Area.	239
Table 7.8 Sensitivity of benefit-cost analysis to changes in input values. Base values are those used in calculation of costs (Table 7.6) and projected benefits (Table 7.7). Percentage change for net regional benefit is relative to the base value of \$4.54million.	240
Table 7.9 Predicted percentiles of: utilisation at four constant stocking rates; and stocking rates at four constant levels of utilisation. Calculations based on pasture growth predictions over a 45 year period (1959/60 to 2003/2004) at Victoria River Downs using the <i>Regional VRD</i> parameter set.	244

Chapter 8

Table 8.1 Summary of the current suitability of GRASP for application to analysis of grazing practices in the VRD when using parameters developed in this study.	251
--	-----

Appendices

Table 9.1 Study sites classified using: ¹ Perry (1970); ² Stewart <i>et al.</i> (1970); and ³ DIPE (unpublished). ..	268
Table 9.2 Study sites classified according to: ¹ Northcote (1979); ² Northcote <i>et al.</i> (1975); ³ Stace <i>et al.</i> (1968); ⁴ Isbell (1996); ⁵ McDonald <i>et al.</i> (1990).	269
Table 9.3 Study sites classified according to Wilson <i>et al.</i> (1990).	270
Table 9.4 Study sites classified according to Tothill and Gillies (1992).	271
Table 9.5 Laboratory analysis results of soil samples from sites located on red earths overlying basalt.	272
Table 9.6 Laboratory analysis results of soil samples from sites located on red earths overlying limestone.	273
Table 9.7 Laboratory analysis results of soil samples from sites located on cracking clays overlying basalt.	273
Table 9.8 Laboratory analysis results of soil samples from sites located on cracking clays of alluvial origin.	274
Table 9.9 Amount of soil nutrients present in surface layers of study sites. (Table continued overleaf).....	275
Table 9.10 Plant species nomenclature for all individual species presented in this study.....	278
Table 9.11 Complete list of plant species present at Site 1, July 1995.....	279
Table 9.12 Descriptive statistics for total standing dry matter data collected at each harvest for all sites. Eight 1m ² quadrats were cut at each harvest. All units are kg/ha. (Table continued overleaf).....	284
Table 9.13 Observed and predicted total standing dry matter (TSDM) values from GRASP model calibration. (Table continued overleaf).....	290
Table 9.14 Summary of results from parameter sensitivity analysis. Data presented is end of growing season pasture TSDM. All units are kg/ha.	297

List of Plates

Appendices

Plate 1 Northern Victoria River District landscape showing escarpment country, woodland plains and alluvial flats.	258
Plate 2 Central Victoria River District landscape showing cattle grazing <i>Chrysopogon fallax</i> and <i>Iseilema spp.</i> pasture on cracking clay soil.	258
Plate 3 Southern Victoria River District landscape showing open grassy plains with scattered trees and occasional rocky basalt outcrops.	259
Plate 4 Land showing evidence of past heavy grazing: bare and scalded ground, dead trees, and annual pasture species.	259
Plate 5 Fencing a study site to exclude cattle from grazing.	260
Plate 6 Burning to remove carryover material at commencement of the study period (Site 16).	260
Plate 7 Marking out sampling cells at site establishment (Site 2).	260
Plate 8 a) Bulk density sampling in soil profile pit; and b) hand-augering soil moisture cores during field measurements.	261
Plate 9 a) Measuring perennial grass basal area using a 5-point frame; and b) pasture sampling during field measurements.	261
Plate 10 Red earth overlying basalt (Site 19).	262
Plate 11 Red earth overlying limestone (Site 11).	262
Plate 12 Cracking clay overlying basalt (Site 4).	263
Plate 13 Alluvial cracking clay (Site 7).	263
Plate 14 Barley Mitchell grass pasture (Site 18).	264
Plate 15 Overhead view of 1m ² quadrat in a) barley Mitchell grass pasture (Site 18); and b) ribbon grass pasture (Site 8).	264
Plate 16 Ribbon grass pasture (Site 8).	264
Plate 17 White grass pasture (Site 14).	265
Plate 18 Overhead view of 1m ² quadrat in a) white grass pasture (Site 14); and b) annual short grass pasture (Site 1).	265
Plate 19 Annual short grass pasture (Site 1).	265
Plate 20 Forb pasture (Site 4).	266
Plate 21 a) Overhead view of 1m ² quadrat in a forb pasture (Site 4); and b) an example of the abundant, diverse forbs present at Site 15 on 2 May 1995.	266
Plate 22 Inundated conditions at Site 15 on 9 March 1995.	266

Plate 23 Annual short grass pasture early in the wet season with no burning at site establishment (Site 13, 12 Jan 1995)..... 267

Plate 24 Overhead view of 1m² quadrats in an annual short grass pasture (Site 13) during early wet season **a**) with no burning at site establishment; and **b**) after burning to remove carryover material..... 267

Plate 25 Annual short grass pasture early in the wet season after site burnt to remove carryover material (Site 13, 9 Jan 1996). Fire most likely destroyed much of the seed bank, resulting in poor germination. 267