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**MANAGING CLIMATIC VARIABILITY IN  
HIGH PERFORMANCE DRYLAND SHEEP  
PRODUCTION SYSTEMS**

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A thesis  
submitted in partial fulfilment  
of the requirements for the degree of  
**Doctor of Philosophy**

at  
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by

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**Lincoln University, Canterbury, New Zealand**

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Abstract of a thesis submitted in partial fulfilment of the requirement for the Degree of  
Doctor of philosophy

## **MANAGING CLIMATIC VARIABILITY IN HIGH PERFORMANCE DRYLAND SHEEP PRODUCTION SYSTEMS**

### **ABSTRACT**

This research investigated the physical and economic impact of incorporating tactical responses in risk management strategies in high performance dryland sheep production systems. An existing grazing sheep simulation model was used in the study. The model was extended by incorporating additional pasture, animal and management modules required in line with the objectives. Seven strategies (S) which differed in the pasture mixes utilised (either grass- or legume-based) and stock class utilised as flexibility options (cattle; grass-based system or old ewes; legume-based system), were evaluated at different stocking rates (SR; stock units (SU) per ha ( $SU\ ha^{-1}$ )), with and without tactical adjustments to trigger soil moisture level (SML) in the top 25 cm soil. Strategy 1 simulated a conventional sheep farm with 13 paddocks of perennial grass:clover mix, 2 paddocks in forage crop (kale) and one paddock into lucerne; strategy 2 was similar to 1 but with 25.0% of the ewes replaced with equivalent cattle stock units; strategy 3 was similar 1 but with introduction of a 1<sup>st</sup> cycle ewe policy; strategy 4 was a combination of strategies 2 and 3; strategy 5 was similar to 3 but with introduction of 2 paddocks of switch pasture and 3 of lucerne; strategy 6 was similar to 4 but with introduction of 2 paddocks of switch pasture and 3 of lucerne; and strategy 7 was similar to 5 but with 5 paddocks of switch pasture and 4 of lucerne. Initially, each of the seven strategies was run at 10, 12, 14 and 16 SR resulting in a 2 factors (7S x 4SR) experiment but without incorporation of tactical adjustments to drop in target SML. In the subsequent analysis, each strategy was re-run with tactical adjustments to the SML target set at 10.0, 12.5 or 15.0% resulting in a 3 factors (7S x 4SR x 3SML) experiment.

In general, lambing percentage was consistently higher in strategy 5 for all the SR considered when the opportunities of incorporating tactical responses in risk management strategies were ignored. However, following inclusion of tactical adjustments to climatic variability, the lambing percentage averaged 137.07% across all strategies and SR. Strategy 4 resulted in the highest meat yield and gross margin (GM) but trailed in wool yield. Results obtained in this study show that coefficients of variability (CV) for lambing percentage increased with increase in SR translating to increased risk with increase in SR in high

performance dryland sheep systems. All strategies incorporating tactical responses were economically superior to those which did not. In some instances, the difference in GM between corresponding strategies with and without including tactical adjustment to climatic variability was as high as 39.65%. In all cases, corresponding risk management strategies incorporating tactical responses to climatic variability resulted in higher GM ( $P < 0.05$ ) and lower risk ( $P < 0.05$ ). The extra income derived from including tactical responses can be viewed as the cost to the farmer of basing choice regarding a management strategy on analysis that neglects the tactical advantages afforded by such a strategy.

**Keywords:** Embedded risk, climatic variability, tactical adjustments, dryland grazing systems, risk management strategies, risk-efficient frontier, cost of climatic variability.

## **DEDICATION**

This work is dedicated to:

My late father Elijah, though departed I continue enjoying your contribution both biologically and materially and fruits of your continued emphasis on the importance of education;

My mother Veronica for the struggle she endured to bring us up and educate us alone, you are a heroine mum;

My wife Joyce, son Titus and daughter Veronica who had to contend with my continued absence from the family and gave me reason to work even harder;

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## TABLE OF CONTENTS

<b>ABSTRACT .....</b>	<b>II</b>
<b>DEDICATION.....</b>	<b>IV</b>
<b>ACKNOWLEDGEMENTS.....</b>	<b>V</b>
<b>TABLE OF CONTENTS.....</b>	<b>VI</b>
<b>LIST OF TABLES .....</b>	<b>X</b>
<b>LIST OF FIGURES .....</b>	<b>XII</b>
<b>LIST OF ABBREVIATIONS.....</b>	<b>XV</b>
<b>CHAPTER 1 .....</b>	<b>17</b>
1.0. Introduction .....	17
1.1. Production Risk in Dryland Grazing Sheep Systems in New Zealand.....	17
1.2. Aim and Objectives of the Research .....	19
1.3. Outline of the thesis.....	20
<b>CHAPTER 2: Literature Review .....</b>	<b>21</b>
2.0. Introduction .....	21
2.1. Risk Analysis.....	21
2.1.1. Sources and responses to Risk.....	24
2.1.2 Resilience .....	25
2.2. Risk Management.....	26
2.3. Farmer Risk Attitudes and Preferences .....	28
2.3.1. Utility and Expected Value .....	29
2.3.2. Assessing Risky Alternatives .....	30
2.4. Embedded Risk.....	31
2.5. Risk sources and management strategies in dryland pastoral systems in New Zealand .....	34
2.6. Managing Grazing Systems.....	37
2.6.1. Modelling Grazing Systems .....	38
2.6.2. Models Classification .....	39
2.7. Grazing System Models .....	41
2.7.1. Pasture Growth Sub-model.....	41
2.7.2. Animal Growth and Composition Sub-model.....	42
2.8. Choice of LincFarm simulation system.....	43
2.9. Model Evaluation .....	44
<b>CHAPTER 3: The LincFarm Simulation Model .....</b>	<b>49</b>

3.0. Introduction .....	49
3.1. Pasture Growth Model.....	49
3.1.1. Growth Sub-models.....	50
Photosynthesis .....	50
3.1.2. Site Dependent Sub-models.....	54
3.1.3. Site and Growth Interactions Sub-models.....	60
3.2. Leaf Death and Litter Disappearance .....	62
3.3. Animal Model.....	63
3.3.1. Animal Reproduction .....	64
3.3.2. Animal Feed Intake .....	65
3.3.3. Maintenance Energy Requirements.....	69
3.3.4. Energy Requirements for Pregnancy and Lactation.....	70
3.3.5. Energy Balance and Nutrition .....	71
3.3.6. Sheep Growth and Composition.....	73
3.3.7. Protein and DNA Synthesis.....	73
3.3.8. Wool Growth.....	74
3.3.9. Predicting Body Weight .....	75
3.3.10. Animal Deaths .....	75
3.4. Farm Management Sub-model .....	76
3.4.1. The Event Calendar .....	76
3.4.2. The Event Records .....	78
3.4.3. Paddock Records .....	88
3.4.4. Block Records .....	88
3.4.5. Mob Records .....	89
3.5. Sampling Records.....	90
3.6. Model Input and Output Data Files .....	90
3.6.1. Model Input Files .....	90
3.6.2. Model Output Files.....	91
3.6.3. LincFarm Model Extension.....	91
<b>CHAPTER 4: Pasture Growth Sub-models.....</b>	<b>93</b>
4.0. Introduction .....	93
4.1. Setting Model Parameters.....	93
4.1.1. Parameter Estimates Obtained from Literature Search .....	97
4.1.2. Preliminary Analysis .....	97

4.1.3. Second Stage Analysis .....	99
4.2. Choice of Parameter Set for Simulating Cocksfoot and Annual Ryegrass Growth ...	100
4.3. Selected Set of Parameters to Model Cocksfoot Growth and Productivity.....	102
4.4. Selected Set of Parameters to Model Annual Ryegrass .....	104
4.5. Choice of Parameter Set for Simulating Lucerne Growth and Productivity .....	107
4.6. Pasture Growth Model Performance Evaluation .....	111
4.7. Choice and Incorporation of Simple Crop Sub-model in LincFarm Model.....	112
4.7.1. Kale DM Accumulation Using Tt Model.....	113
4.7.2. Leaf Turnip DM Accumulation.....	114
4.7.3. Rape DM Accumulation.....	115
<b>CHAPTER 5: Beef Growth and Composition Sub-model .....</b>	<b>118</b>
5.0. Introduction .....	118
5.1. Model Description .....	118
5.2. Test Simulation One .....	120
5.3. Test Simulation Two .....	127
5.4. Beef Growth and Composition Model Performance Evaluation.....	130
5.5. Incorporation of the Beef Sub-model in LincFarm Model.....	133
5.6. Conclusion .....	133
<b>CHAPTER 6: A Destocking and Marketing Algorithm.....</b>	<b>134</b>
6.0. Introduction .....	134
6.2. Design, Development and Implementation of the Destocking Algorithm .....	135
6.2.1. Inclusion of a ‘Severity Index’ .....	139
6.3. Results .....	146
6.4. Conclusions .....	148
<b>CHAPTER 7: Evaluation of the Extended LincFarm Model .....</b>	<b>149</b>
7.1. Introduction .....	149
7.2. Silverwood Innovative Sheep Systems Trial (SISST).....	149
7.2.1. Grass Farm System.....	151
7.2.2. Legume Farm System.....	152
7.3. Simulation Runs .....	152
7.3.1 Climate Data .....	155
7.4. Results .....	156
7.2. Conclusion on the Evaluation of Extended LincFarm Model .....	162
<b>CHAPTER 8: Evaluation of Alternative Risk Management</b>	

<b>Strategies .....</b>	<b>163</b>
8.0. Experimental Protocol .....	163
8.1. Climate and Price Data Analysis .....	164
8.1.1. Silverwood Farm VCS Rainfall and Temperature Data.....	164
8.2. Relationship between Lamb Price and Rainfall Changes.....	166
8.3. Risk Management Strategies .....	168
8.4. Tactical Responses .....	169
8.5. Results .....	170
8.5.1. Annual pasture production .....	170
8.5.2. Lambing percentage .....	171
8.5.3. Meat and wool production.....	171
8.5. Effect of Including Tactical Responses within Strategies on Production .....	172
8.7. Profit and risk .....	173
8.8. Sensitivity of gross margin to changes in prices of meat and wool .....	185
<b>CHAPTER 9: Discussion, Conclusions and Further Research</b>	
<b>Recommendations.....</b>	<b>187</b>
9.1. The Rationale for this study .....	187
9.2. Methodological approach .....	187
9.3. Evaluation of alternative risk management strategies .....	189
9.4. Implication of including tactical adjustments in risk management strategies .....	192
9.4.1. The value of tactical responses and/or cost of variability .....	192
9.5. The risk-efficient frontier .....	194
9.6. Sensitivity of GM to meat and wool price changes.....	195
9.7. Choice of trigger variable and its value.....	196
9.8. Factors contributing to increased productivity and profitability of alternative risk-efficient strategies .....	197
9.9. Conclusions .....	200
9.10. Recommendations for future research .....	201
<b>References .....</b>	<b>202</b>
<b>Publications in the course of study .....</b>	<b>227</b>

## LIST OF TABLES

<b>Table 2.1:</b> Economic concept of utility example.....	29
<b>Table 3.1:</b> Radiation parameters utilised in Bywater <i>et al.</i> (1999) model.....	55
<b>Table 3.2:</b> Soil moisture parameters utilised in Bywater <i>et al.</i> (1999) model.....	58
<b>Table 3.3:</b> Values of FC and AWHC used in Bywater <i>et al.</i> (1999) water stress model.....	61
<b>Table 3.4:</b> Lamb birth weight (kg) .....	70
<b>Table 3.5:</b> Data structure used in the model.....	77
<b>Table 3.6:</b> List of events identifiers, description and target group.....	79
<b>Table 4.1:</b> Parameters estimates for cocksfoot and annual ryegrass .....	94
<b>Table 4.2:</b> Parameters within the pasture model with considerable influence on ESS for TDM, GDM, LM, and the sum of their ESS for ryegrass and cocksfoot.....	99
<b>Table 4.3:</b> Germination sub-model parameters .....	105
<b>Table 4.4:</b> Parameter estimates for simulating lucerne growth and productivity.....	109
<b>Table 4.5:</b> Statistics for the set of pasture model parameters <sup>1</sup> used in simulating yield (kg ha <sup>-1</sup> ) of cocksfoot, annual ryegrass and lucerne .....	112
<b>Table 5.1:</b> Un-optimised parameter estimates of the growth and composition model of Oltjen <i>et al.</i> (2006) .....	122
<b>Table 5.2:</b> Estimates of the growth and composition parameters for cattle based on the data of Kitessa (1997) experiment I .....	125
<b>Table 5.3:</b> An inverse of a simple correlation matrix amongst model parameters fitted for the Kitessa (1997) experiment I data.....	126
<b>Table 5.4:</b> Comparison of model predictions (Pred.) and data of Sainz <i>et al.</i> (1995) (Obs.) and their percentage differences (% dif.) for EBW, protein, fat and viscera components of the final slaughter group.....	132
<b>Table 6.1:</b> Destocking and marketing policies decision rules table for the hypothetical farm .....	145
<b>Table 7.1:</b> Model farm description and variables.....	154
<b>Table 7.2:</b> Summary validation statistics for the pasture model against pasture cover data for grass- and legume-based trial farm units .....	158
<b>Table 7.3:</b> Summary validation statistics for the pasture model against switch pasture and lucerne pasture growth rate data from Silverwood legume-based trial unit.....	160
<b>Table 7.4:</b> Comparison of observed cattle sale and corresponding model LW on the grass system unit.....	161
<b>Table 8.1:</b> Lambing percentage for strategies 1-7 without incorporating tactical	

adjustments to climatic variability (the italicized values in parenthesis are coefficient of variation) .....	171
<b>Table 8.2:</b> Meat and wool production for strategies 1-7 at 10, 12, 14 and 16 SR without incorporating tactical adjustments to climatic variability (italicized values in parenthesis are coefficient of variation) .....	172
<b>Table 8.3:</b> Increase in average meat yield for strategies 1-7 at 10, 12, 14 and 16 SR with inclusion of tactical responses at trigger levels of 10.0, 12.5 and 15.0% volume of soil moisture in top 25.0 cm soil .....	173
<b>Table 8.4:</b> A sample gross margin report; results were averaged over fifteen years period. Range figures represent the minimum and maximum for each row obtained over fifteen years period.....	174
<b>Table 8.5:</b> Gross margin (\$ ha <sup>-1</sup> ) for strategies 1-7 at 10, 12, 14 and 16 SR without tactical adjustments to climatic variability (italicised values in parentheses are coefficients of variation) .....	175
<b>Table 8.6:</b> Gross margin for Strategies 1-7 at 10, 12, 14 and 16 SR with tactical adjustments to climatic variability (italicised values in parentheses are coefficients of variation) .....	177
<b>Table 8.7:</b> Summary analysis of variance statistics for GM.....	178
<b>Table 8.8:</b> Summary analysis of variance statistics for risk .....	179
<b>Table 8.9:</b> Percentage increase in gross margin between corresponding strategies 1-7 at 10, 12, 14 and 16 SR with inclusion of tactical responses at 10, 12.5 and 15.0% SML by volume in top 25.0 cm soil) .....	180
<b>Table 8.10:</b> Percentage decrease in coefficients of variation between corresponding strategies 1-7 at 10, 12, 14 and 16 SR with inclusion of tactical responses at 10, 12.5 and 15.0% SML by volume in top 25.0 cm soil) .....	181
<b>Table 8.11:</b> Results for treatments mean difference.....	184
<b>Table 8.12:</b> Optimal tactical decisions table used in obtaining the risk-frontier presented in Figure 8-6B .....	185
<b>Table 8.13:</b> Gross margin at different prices <sup>1</sup> of meat and wool for strategy 4 at 14 SR with/without inclusion of tactical responses to drop in SML to 10.0, 12.5 and 15.0% in top 25.0 cm soil.....	186
<b>Table 9.1:</b> A list of strategies with and without incorporating tactical responses in risk management falling on the risk-efficient frontier.....	195

## LIST OF FIGURES

<b>Figure 2-1:</b> Decision tree (Source, Kay and Edwards, 1999)	27
<b>Figure 2-2:</b> Embedded and non-embedded risk decision tree (Hardaker <i>et al.</i> , 1991)	32
<b>Figure 2-3:</b> Tactical responses to uncertainty (Dorward and Parton, 1997)	33
<b>Figure 3-1:</b> Diagrammatic representation of the mechanistic pasture growth model	50
<b>Figure 3-2:</b> Diagrammatic representation of the soil moisture status sub-model	58
<b>Figure 3-3:</b> Diagrammatic representation of the farm management sub-model. Ellipses represent list of records, boxes show single records, hexagon represent sub-models, and lines depict relationships	76
<b>Figure 4-1:</b> Histogram of the ESS for TDM, GDM, LM and the summed ESS of the three components for each parameter value when that parameter value is 0.9 of the base line value for cocksfoot	98
<b>Figure 4-2:</b> Total ESS of TDM, GDM and LM for moderately (A) and highly (B) sensitive parameters as this parameter value changes	100
<b>Figure 4-3:</b> Plots of model output for cocksfoot growth rate compared to observed growth data obtained from field experiment for cocksfoot	103
<b>Figure 4-4:</b> A comparison between simulated cocksfoot yield and data (A) for different periods in different years in relation to temperature (B)	104
<b>Figure 4-5:</b> A comparison between simulated annual ryegrass yield and data for different periods in different years	106
<b>Figure 4-6:</b> A comparison between simulated annual and perennial ryegrass pastures growth for different seasons (A) and yield for different months (B)	107
<b>Figure 4-7:</b> Plots of model output for lucerne growth rate compared to observed growth data obtained from field experiment	111
<b>Figure 4-8:</b> Observed and model predicted values for kale DM accumulation	114
<b>Figure 4-9:</b> Observed and model predicted values for Pasja DM accumulation	115
<b>Figure 4-10:</b> Observed and model predicted values for rape DM accumulation	116
<b>Figure 4-11:</b> Kale DM accumulation in a season receiving an average amount of rainfall (average year) and one experiencing a less than average rainfall	117
<b>Figure 5-1:</b> Effects (%) of varying model parameters by 30 (■) and (■) 90% respectively on $f$ (A), $v$ (B), $m$ (C), components, and LW (D)	122
<b>Figure 5-2:</b> The effect of varying parameters obtained from Oltjen <i>et al.</i> (2006) on SS for the data of Kitessa (1997) experiment I.	125
<b>Figure 5-3:</b> Model EBW mass, protein and % protein	127

<b>Figure 5-4:</b> Percentage difference between model EBW mass and components using parameters obtained in the current study and those used in Oltjen <i>et al.</i> (2006)	128
<b>Figure 5-5:</b> Model-predicted Hp for maintenance for five treatment groups of Sainz <i>et al.</i> (1995)	130
<b>Figure 5-6:</b> Observed and predicted values for average LW for animals in data obtained from Kitessa (1997) experiment II utilising published parameters in Oltjen <i>et al.</i> (2006), ▲ ; and parameters estimated in this study, ○ -----. The thick line is the $y=x$	131
<b>Figure 5-7:</b> Observed (Sainz <i>et al.</i> , 1995) and predicted values for EBW mass (A), muscle (B), fat (C) and viscera (D).The thick line is the $y=x$	131
<b>Figure 5-8:</b> Mean squared deviation (MSD, kg) and its components; lack of correlation weighted by the standard deviation (LCS), squared difference between standard deviations (SDSD), and squared bias (SB) in comparison of LW simulations for 8 different animals	132
<b>Figure 6-1:</b> The destocking and marketing algorithm	136
<b>Figure 6-2:</b> The four potential animal feed demand and supply scenarios (A, B, C and D) under a grazing system	138
<b>Figure 6-3:</b> Results from the destocking and marketing algorithm feed profiles	139
<b>Figure 6-4:</b> Feed profile for a farm situation where the three severity circumstances are encountered as indicated on the graph	141
<b>Figure 6-5:</b> Stock type disposal priority for the hypothetical farm with the progression of the season	143
<b>Figure 6-6:</b> Animal number retained on farm when 100 (A), 75 (B), 50 (C) and 25% (D) of required feed is available for the non-capital stock	147
<b>Figure 6-7:</b> Total feed consumed by each stock category retained on farm when 100 (A), 75 (B), 50 (C) and 25% (D) of required feed is available for the non-capital stock	148
<b>Figure 7-1:</b> A comparison of weather data obtained from Silverwood farm VCS and three years data obtained from the Silverwood farm for temperature (A), rainfall (B), radiation (C) and wind run (D)	155
<b>Figure 7-2:</b> Comparison of simulated pasture covers for the grass- (A) and legume-based (B) systems compared with data from Silverwood grass and legume trial units for the production period 2007/08 to 2009/10	157

<b>Figure 7-3:</b> Comparison of simulated growth rate for switch pasture (A) and lucerne (B) with observed data from Silverwood grass and legume farm units	159
<b>Figure 7-4:</b> Comparison of simulated kale yield with observed data from Silverwood trial farm units for production period 2008/09 (A) and 2009/10 (B)	161
<b>Figure 8-1:</b> Total annual rainfall and temperature at Silverwood VCS for the period 1991-2009	165
<b>Figure 8-2:</b> Variability in monthly average rainfall at Silverwood farm VCS for the period 1991-2009	166
<b>Figure 8-3:</b> A comparison between lambs price and total annual rainfall for the period 1994-2009	167
<b>Figure 8-4:</b> Pasture production for strategies 1-7 at 10, 12, 14 and 16 SR	170
<b>Figure 8-5:</b> Gross margin for strategies 1-7 at 10, 12, 14 and 16 SRs	176
<b>Figure 8-6:</b> Relationship between expected gross margin and variability as measured by standard deviation for risk management without (A) and with (B) incorporation of tactical response to climatic variability	183
<b>Figure 9-1:</b> Lamb growth rates for years 1995-2009 for strategy 2 run at 10, 12, 14 and 16 SR at 10.0% SML	198
<b>Figure 9-2:</b> Average daily pasture intake for strategy 2 run at 10, 12, 14 and 16 SR at 10.0% SML	199

## LIST OF ABBREVIATIONS

Abbreviation	Description
AGMARDT	Agricultural Marketing Research and Development Trust
ALW	average lamb live weight
APF	animal parameters file
BDF	base definition file
CE	certainty equivalent
CV	coefficients of variability
DGM	Davis Growth Model
DM	dry matter
DMI	dry matter intake
DMS	dynamic management system
DW	drafting weight
EBW	empty body weight
E	expected value
EMV	expected monetary value
$E_p$	expected gross margin
EXP	experiment
FDF	farm description file
FEC	faecal egg count
GM	gross margin
Ha	hectare
ID	identifier number
LCS	lack of positive correlation
LWG	live weight gain
LW	live weight
MAF	Ministry of Agriculture
MB	mean bias
MEI	metabolisable energy intake
MP	mathematical programming
MSD	mean squared deviation
MSEP	mean square error of prediction
MSV	mean squared variation
MUDAS	Model of Uncertain Dryland Agricultural System
$NE_g$	net energy of gain
NIWA	National Institute of Water and Atmospheric Research Ltd
NUT	nutrition
PGP	plant growth parameters

Abbreviation	Description
RMSD	mean square deviation
SB	squared deviation
SD <sub>m</sub>	standard deviations of the measurement
SDSD	squared difference between standard deviations
SD <sub>s</sub>	standard deviations of the simulation
SD	standard deviation
SEU	subjective expected utility
SI	severity index
SISST	Silverwood innovative sheep systems trials
SML	trigger soil moisture level
SR	stocking rate
S	strategy
SU	stock units
TNC	total non-structural carbohydrate
Tt	thermal time
VCSN	virtual climate station network
VIF	variance inflationary factors
V	variance
WW	weaning weight

## CHAPTER 1

### 1.0. Introduction

The New Zealand economy is based on agricultural production and export, with agriculture in turn being dominated by livestock production systems based on grazed pasture (Carracelas *et al.*, 2008). Given this high dependence on pastoral agriculture and an increasing demand for high quality food, fibre and health-related products from the world's burgeoning middle class, the challenge is to increase pastoral agricultural productivity.

### 1.1. Production Risk in Dryland Grazing Sheep Systems in New Zealand

Livestock production in New Zealand is based on pasture and forage for all classes of ruminants (Carracelas *et al.*, 2008). The two main islands of New Zealand have a combined land area of 26.4 million hectares (ha) of which 15.6 million ha (59.0%) is under agricultural use. Nearly 12 million ha (77.0%) of this agricultural land is grazed by livestock, making pastoral farming the dominant land use which accounted for 44.0% of the total dollar value of New Zealand's exported merchandise in 2004 (Bourdôt *et al.*, 2007).

Pastoral agriculture is vulnerable to climatic variability (Halloy and Mark, 2003; Thornley and Cannell, 1997). As an extreme example, the 1988-1989 drought is estimated to have cost the east coast of the North Island \$240 million in reduced income and the total region \$1000 million (Nield, 1990). Climate is an important driving factor in determining pasture ecosystem processes and principally controls the biomass availability and distribution (Bai *et al.*, 2004; Barrett *et al.*, 2002). Radcliffe and Bars (1987) identified rainfall as the main climatic factor constraining pasture production in New Zealand, with spring and summer rainfall accounting for 60.0% of the variation in pasture production. Baars and Waller (1979) had also identified rainfall and temperature as climatic variables influencing pasture production, with temperature playing an important role in pasture growth especially in winter and early spring. This view was also held by White (1990). Climatic variation affects both feed availability and nutritional quality. Thus grazing livestock production is constrained by the amount, seasonality and annual variability of forage production (Oesterheld *et al.*, 1992; Diaz-Solis *et al.*, 2006). This within- and between-season variability in feed availability and quality introduces uncertainty and risk into pastoral livestock systems which significantly complicate their management.

Efficient pastoral production aims at maintaining and/or improving pasture and animal performance within the constraints of the socio-economic and biophysical environments (Ramírez-Restrepo *et al.*, 2006). Setting stocking rate (SR) is the principal managerial

decision in these systems (Diaz-Solis *et al.*, 2003, 2006) but a variety of other short- or medium-term management options are available (Webby and Bywater, 2007). A series of trials has recently been concluded which set out to investigate and demonstrate key elements of high productivity sheep systems in dryland conditions in Canterbury (the Silverwood trials; Bywater *et al.*, 2010). These trials included alternative forage systems designed to provide high pasture quality and utilisation based primarily on a relatively high SR for the district in order to keep pastures in an actively growing state. A high stocking rate increases risk in such a variable environment so a central part of the trial was the inclusion of a series of options which provide the flexibility to alter feed demand, and to a lesser extent supply, in response to changes in climatic conditions during the season.

Finlayson *et al.* (1995) noted the complexity of managing grazing system in regards to the need to balance the nutritional requirement of different classes of livestock with a feed supply that fluctuates in quality and quantity within and between years. The complexity of farming systems and the uncertainty involved with decision making process are key features which emphasise the importance of a systems approach to studying and understanding agricultural systems. Systems theory is primarily concerned with the systematic study of interactions between the different factors (subsystems) that make up the system with the notion that the whole is more than the sum of the parts (Doyle, 1990). The early development of systems theory linked it with the use of models. Various agricultural systems models have been reported including those of Csaki (1985), Oriade and Dillon (1997), Cacho *et al.* (1999), Ekman (2002), Chen (2004), and Zhai (2006).

To be useful in pastoral agriculture, models must account for variability and/or risk. Risk in agricultural systems constitutes the uncertainty involved with a decision making process. Anderson *et al.* (1977) stated that there is little distinction between risk and uncertainty. Those who argue that risk and uncertainty are essentially the same suggest that even if the ranges of possible outcomes are known, the probabilities put on the likelihood of the outcomes are to some extent subjective.

A common assumption especially in modelling risk management in agriculture is that there is a risk or a source of risk that a decision is made to minimise, eliminate or accept. The assumption is that a single management decision is made at a point in time and from there the situation unfolds (Antle, 1983). This denies the farmer and/or manager the opportunity to respond to a risk or uncertainty as it unfolds which may lead to better outcomes than would be possible from taking a single strategic response. Dorward (1994) introduced the concept of embedded risk to reflect a farmer's ability to respond sequentially. The idea was to adapt non-

sequential multi-state linear programming models into a semi-sequential framework. The concept of embedded risk should be considered when evaluating alternative strategies for managing variability in pastoral livestock systems and the opportunity clearly exists to address this aspect with a model that is able to implement alternative tactical interventions in response to climatic conditions as they unfold.

The farm systems model LincFarm (described in details in Finlayson *et al.* (1995) and Cacho *et al.* (1995)) is designed to evaluate alternative strategies for managing pastoral sheep systems. It includes a management calendar which allows for some interventions to be conditional on prevailing conditions within the simulation. For example, both the conservation of surplus pasture and feeding of conserved feeds can be conditional on current pasture supply and animal feed requirements.

## **1.2. Aim and Objectives of the Research**

The overall aim of the research project which is reported in this thesis was to evaluate alternative strategies and tactical responses for managing the risks of fluctuating soil moisture (rainfall), temperature, pasture growth and utilisation, and market prices for increased productivity and profitability in high performance dryland sheep systems. The analysis is based on the Silverwood dryland sheep systems trials reported by Bywater *et al.* (2010) and uses the LincFarm sheep systems model to evaluate alternative strategies and tactical responses. While LincFarm contains sub-models for a number of pasture species, there were some species included in the Silverwood trials which are not currently included in LincFarm and there is no facility to include beef cattle which were one of the options included in the trials.

Specific objectives were therefore to:

1. parameterise a mechanistic pasture growth model for annual ryegrass, cocksfoot and lucerne
2. identify and parameterise a beef growth and composition simulation model suitable to predict grazing beef performance in New Zealand grazing conditions
3. design, implement, evaluate and incorporate a destocking and marketing algorithm usable in LincFarm for simulating tactical responses
4. evaluate alternative risk management strategies and tactical responses to increase productivity and profitability in high performance dryland sheep systems
5. identify critical decision variables to be monitored and establish trigger values for intervention

### 1.3. Outline of the thesis

The research is divided into 9 chapters with **Chapter 1** and **Chapter 2** presenting the introduction and literature review respectively. **Chapter 3** describes the design and working of the LincFarm grazing sheep system simulation model used as a basis for evaluating alternative policies and risk management responses within high performance dryland sheep systems. Several extensions to the existing model have been developed for the current analysis. This chapter describes the model as it was prior to the commencement of this study. **Chapter 4** presents the growth and productivity model parameter values for the annual ryegrass, cocksfoot and lucerne and the procedure followed in their estimation. **Chapter 5** describes the processes of identification and parameterisation of a suitable beef growth and composition sub-model for New Zealand dryland grazing conditions. **Chapter 6** describes an algorithm developed to carry out destocking and marketing decisions where productivity and profitability are highly influenced by climatic variability. The algorithm allowed an evaluation of different tactical responses to climatic conditions within high performance dryland sheep systems. **Chapter 7** details the process of evaluation for the extended LincFarm model. The original LincFarm model evaluation had been carried out to identify and correct deficiencies in its predictive performance in simulating a grazing sheep system. However, new aspects (animal, pasture and management) have been introduced in the model in line with the objectives of this study. Therefore, there was a need to carry out evaluation tests for the newly introduced aspects to correct for any identifiable deficiency. **Chapter 8** describes the model input data, experimental protocol, risk management strategies and tactical responses, and results for various strategies and tactical responses evaluated in this study. Finally, **Chapter 9** presents discussions, conclusions and recommendations for further research.

## CHAPTER 2

### Literature Review

#### 2.0. Introduction

In New Zealand, seasonality in herbage production primarily drives lamb production. Ewes are normally mated in autumn (March–May) with an objective of matching lambing with the spring pasture flush. Lambs are ready for slaughter throughout the summer and autumn (December–May) (Morris *et al.*, 1993). Despite the important economic role played by pastoral agriculture, grazing production systems are constrained both biophysically and economically by the amount, seasonality and annual variability of forage productivity (Ramírez-Restrepo *et al.*, 2006) as a result of climatic variability which has a major impact on the productivity and profitability of livestock farms (Diaz-Solis *et al.*, 2006).

Improvement and/or maintenance of pasture and animal performance are the main goals of efficient pastoral production systems (Ramírez-Restrepo *et al.*, 2006). Achieving efficiency is complex in regards to the need to balance the nutritional requirement of different classes of livestock with a feed supply that fluctuates in quality and quantity between and within years (Finlayson *et al.*, 1995). In most grazing livestock production enterprises, management interventions geared towards maximizing productivity and profitability are achieved through increasing the stock units (SU ha<sup>-1</sup>) and lambing percentage (Bywater *et al.*, 2010). However, increasing these two parameters is expected to result in higher demand for feed and where weather is a highly variable limiting factor, increasing risk.

Managing climatic variability by short-term manipulation of feed supply and/or animal feed requirement offers an opportunity in such systems (Webby and Bywater, 2007). In times of surplus, pasture conservation or operating additional livestock units would be appropriate. In times of shortage, reducing the number of stock or providing additional feed are alternative options. A model farm with potential for the application of the tactical responses to climatic variability within a season was developed for a high performance sheep farming system within which alternative risk management policies were tested in this study.

#### 2.1. Risk Analysis

Risk from the dictionary perspective is the possibility of incurring misfortune or loss<sup>1</sup>. Harwood *et al.* (1999) in their study defined risk as the possibility of adversity or loss, and referred to risk as “uncertainty that matters”. Further definition of risk as a situation in which

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<sup>1</sup>Collins Concise Dictionary 3<sup>rd</sup> Edition, 1995

more than one possible outcome exists, some of which may be unfavourable came from the study by Kay and Edwards (1999). However, it was the work by Hardaker (2000) which gave the three common interpretations of risk namely a chance of a bad outcome, a variability of outcome and uncertainty of outcomes.

Hardaker (2000) interpretation of risk as a chance of a bad outcome implies the probability of some undefined unsatisfactory outcome occurring. For example, assuming there is a single measure of outcome denoted  $X$  much of which is always preferable to less. The chance of bad outcome definition could be represented by the following probability:

$$P^* = p(X \leq X^*) \quad (2:1)$$

where  $P$  is probability,  $X$  is the uncertain outcome, and  $X^*$  is some cut-off or minimally acceptable outcome level below which outcomes are regarded as 'bad' and  $P^*$  denotes the probability of  $X^*$  occurring. In some cases, the value  $X^*$  might reflect some disaster level such as 'insolvency', however more often this may be a less clear-cut notion, with application of this measure of risk favouring specification of the two parameters  $P^*$  and  $X^*$ .

Hardaker (2000) interpretation of risk as variability can be measured statistic of dispersion of the distribution of outcomes, such as the variance ( $V$ ) or standard deviation ( $SD$ ) of the uncertain outcome:

$$V = V[X] \quad (2:2)$$

or:

$$SD = \sqrt{V} \quad (2:3)$$

However, neither  $V$  or  $SD$  provide information on the location of the distribution of outcomes on the  $X$  axis necessitating use of the dispersion statistics to link  $V$  or  $SD$  with the mean or expected value ( $E$ ) as:

$$E = E[X] \quad (2:4)$$

Variance may then be described as the risk around the specified mean. Newbery and Stiglitz (1981) extended the notion to reflect risk using the coefficient of variation ( $CV$ ) of  $X$ :

$$CV = \frac{SD}{E} \quad (2:5)$$

In order to define risk as the distribution of outcomes the whole distribution of  $X$  needs to be specified with a complete specification requiring the probability density function,

$f(X)$ , or equivalent and often more conveniently, the cumulative distribution function  $F(X)$ . However, in practice summary statistics including moments are commonly used to describe the probability distribution. This means there are some similarity with the measurements based on the definition of risk as dispersion. In such cases as the normal, the distribution of outcomes is completely defined by only the mean and variance. Few other other distributions might be approximated in terms of mean and variance, though higher order moments may be needed to tell more about the shape of the distribution.

The limitation of defining risk as a chance of a bad outcome or variability of outcome (Hardaker, 2000) and their associated measures is that neither gives the whole picture especially when a choice has to be made amongst many risky alternatives. In regard to risk as a chance of a bad outcome,, it is evident from observing behaviour that not all risks with bad outcomes are rejected. For example, many people travel by car to for sightseeing with the knowledge that there is increased probability of death or serious injury in case of a road accident. Apparently, choices with chances of very bad outcomes such as death or serious injury are at times accepted, assumingly because the benefits of the up-side consequences such as seeing interesting sights are sufficiently attractive to offset the relatively low chances of the bad outcome. Subsequently, to evaluate or asses a risk there is need to consider the whole range of possible outcomes, good and bad, and their respective probabilities. Therefore, as suggested by Hardaker, (2000), expressing risk in terms of only the probability in the lower limit of the distribution of outcomes does not provide full information for proper risk assessment and may thus be seriously misleading.

Risk and uncertainty have received different reactions and definitions from different authors. For instance, Knight (1921) suggested an existence of three states or ‘categories’ of knowledge in decision-making situations: perfect knowledge, risk, and uncertainty. The suggestion was that risk is variability of an outcome with known probabilities, while uncertainty is variability of an outcome with unknown probabilities. Other authors such as Anderson *et al.* (1977) recognised little difference between risk and uncertainty. Anderson *et al.* argued that all probabilities in decision making are subjective and thus the difference between risk and uncertainty becomes insignificant. For the purposes of this study, risk and uncertainty are treated as the same; risk and/or uncertainty are considered in general as the variability of outcomes, i.e. the converse of stability and are referred to as either risk or variability throughout the study. This has a significant impact on what constitute good climatic variability management strategies to be considered and good risk management in general.

### **2.1.1. Sources and responses to Risk**

Various potential sources of risk in agriculture have been identified. MAFF (2001) summarised risk into production, price or market, currency, institutional, financial, legal, and personal. Waterman (2002) classified sources of risk into just five categories as production, marketing, financial, legal or human resource. Production risk comes from the unpredictable nature of weather and uncertainty about the performance of crops and/or livestock. Marketing risk refers to the uncertainty of prices of farm inputs and outputs. Farmers are increasingly being exposed to unpredictable competitive markets for inputs and outputs (MAFF, 2001). Currency risk as noted in MAFF (2001) relates to the revaluation or devaluation of the national currency which affects export and imports demand and domestic prices for competitively traded inputs and outputs. New Zealand agriculture is export oriented making currency risk an important aspect when designing a farm model.

There are a number of basic responses to risks in agriculture. A decision maker can respond by accepting the risk, transferring the risk via insurance or contracts, or by eradicating or managing the risk by putting in place risk reduction strategies. Waterman (2002) suggested five responses to risk as retain, shift, reduce, self-insure and avoid. Barry (1984) had summarised risk responses into four basic categories as either being production, marketing, financial or integrated. Examples of production risk responses include development of a decision support system for predicting seasonal rainfall variation (Hutchinson, 1996) and a decision support system on the impact of planting drought resistant pasture (Korte and Rhodes, 1993) in management of climatic variability. Similarly, various marketing risk response options exist; examples include forward contracting with the buyer of the crop or livestock, spreading sales throughout the season, or hedging (Battles and Thompson, 2000). A financial response could be to carry a large cash reserve to protect the business from a failed crop or a poor season. An integrated response would be a combination of any or all of the listed responses. In managing climatic variability in high performance dryland sheep systems, a range of alternative risk management options will be explored.

All risk responses, however, come at a cost (Patrick, 1992). For instance, a decision to forward contract the sale of lambs could mean that if the price of the lamb increases, the farmer would be losing out on potential extra income. The decision to carry a large cash reserve or to limit the level of borrowings may limit the potential rate of growth of the business. It is this complexity in decision making that emphasises the need for simulation models to evaluate and identify optimal strategies. For a farm model to be relevant it should account for such tactical responses to risk to optimise productivity and profitability. This is

the main focus of this study.

### **2.1.2 Resilience**

Gunderson and Holling (2001) define resilience as the ability of a system (e.g. ecosystems, societies, corporations, nations and socio-ecological systems) to undergo a disturbance and maintain its functions and control. They considered resilience as a measure of the magnitude of disturbance a system can tolerate and still persist. This is different to the concept previously advanced by Pimm (1984) and Tilman and Downing (1994) as a system's ability to resist disturbance and the rate at which it returns to equilibrium following disturbance. Carpenter *et al.* (2001) observed that the distinction between the two definitions of resilience has been useful in encouraging the managers of naturally variable systems (e.g. dryland pastoral systems) to move away from concentrating on management aimed at the unachievable goal of stability. However, it is important to simultaneously consider resistance which is a complementary aspect of resilience. Carpenter *et al.* (2001) defines resistance as the amount of external pressure needed to bring about a given amount of disturbance in the system.

According to climate change research by Kenny and O'Brien (2007), farmers will encounter increasing climatic extremes and it is important therefore to design farming systems that will cope with the increased climatic extremes and variability (Crawford *et al.* 2007). Resilient farming systems would take advantage of the three properties conceived by Holling (1973, 1996), that is the amount of change the system can undergo and still retain the same functions and control, the degree to which the system is capable of self-reorganization, and the degree to which the system can build the capacity to learn and adapt (such as use of available information and tools in implementing flexibilities in dryland pastoral systems). These three properties have been explored further by Rusito *et al.* (2011) who identified buffer capacity, adaptive capacity, and transformability as three elements that allow the manager to respond to different degrees of change in the production environment. Conway (1993) defined buffer capacity as the constancy of system productivity when subjected to small disturbances as a result of fluctuations and cycles in the production environment. Adaptive capacity was defined by Brooks (2003) as the capacity of a system to respond to a change or shift in the environment to cope better with existing or anticipated external shocks. Carpenter *et al.* (2001) however, do not distinguish between resilience and adaptive capacity and have used these terms interchangeably. Transformability was defined by Darnhofer *et al.* (2010) as the ability of a manager to find new ways of organising resources when the disturbance in the production environment is extreme enough to compromise the current

system.

Rusito *et al.* (2011) recognised that resistance, described by Carpenter *et al.* (2001) as the amount of external pressure needed to bring about a given amount of disturbance in the system, measured as efficiency, the degree to which the system is capable of self-reorganization (Holling, 1973, 1996) measured as liquidity, and vulnerability which was defined as the potential for loss by Luers *et al.* (2003) and measured as solvency in Rusito *et al.* (2011) are useful indicators of buffer capacity. Rusito *et al.* (2011) argued that highly efficient systems are characterised by higher resistance, and that farms with good liquidity have more ability to reorganize themselves (return to the original state) following a shock. In a study of the resilience of New Zealand dairy farm business from 2006–2009, a period characterised by wide fluctuation in milk price, Rusito *et al.* observed that farmers who took best advantage of upside price risk did not cope well with downside price risk. This implies that the portfolio of risk management strategies used by farmers to respond to upside price risk did not align well with downside price risk management. Their study underlines the importance of risk management portfolios whose strategies take advantage of the upside risk while at the same time minimising downside risk.

The current study was set to take advantage of both upside risk (stock for better than average growing conditions) and downside risk (retreat by sale of animals as and when conditions dry out) resulting from climatic variability. Alternative risk management portfolios are identified (in the form of risk-efficient strategies) from which farmers with different production objectives and preferences can choose. The portfolios differ in pasture types and combinations, flexible stock class combinations (saleable animals maintained in the system), and soil moisture levels to trigger stock sale decisions.

## **2.2. Risk Management**

Risk management as defined by Landcare Research (2003) is the culture, processes, and structures that are directed towards the effective management of potential opportunities and adverse effects. In an agricultural setting, risk can be defined as choosing among alternatives that reduce the financial effects of the uncertainties of weather, yields, prices, government policies, global markets, and other factors which can cause variations in farm income (MAFF, 2001).

Jolly (1983) suggested that as all actions that might be taken by a farmer are subject to risk, there is no distinction between farm management and what is historically called risk management. In many ways all decisions made in agricultural systems, are made with imperfect knowledge about the outcomes. A crop is selected, sown, managed and harvested in

weather conditions that are uncertain at sowing. A yield of unknown quality is harvested and after all this, the product is then sold at what may be an unknown price. These unknowns make efficient resource allocation decisions difficult.

Since agricultural production occurs in a risky environment, there is a need to make decisions on how to manage the risk. Until mid 1990's, priority with respect to analysing risky decisions has been placed mostly on choice of farming strategy and on accounting for the effects of attitude to risk (Kingwell *et al.*, 1993; Pannell *et al.*, 1995).

A decision tree obtained from Kay and Edwards (1999) is presented to describe the effects of attitude to risk on choice of strategy. The decision tree (Figure 2-1) represents three stocking options, to buy 300, 400 or 500 steers. The next step in the decision tree relates to factors outside the farmer's control, the weather in this case for which it is assumed there are just three scenarios resulting in good, average, or poor growth. The probability of good growth is 0.2, of average growth 0.5 and of poor growth 0.3. For each of the three stocking options and the three possible weather circumstances at their probabilities there is net return. The net return range from \$34,000 where 500 steers are purchased and favourable weathers follow to a loss of \$10,000 where 500 steers are purchased and the weather condition is not favourable.

Strategy	Weather outcome	Probabilities		Net returns	Expected Value
Buy 300	Good	0.2	x	\$20,00	\$4,000
	Average	0.5	x	\$10,000	\$5,000
	Poor	0.3	x	\$6,000	<u>\$1,800</u>
					<b>\$10,800</b>
Buy 400	Good	0.2	x	\$26,000	\$5,200
	Average	0.5	x	\$14,000	\$7,000
	Poor	0.3	x	\$0	\$0
					<b>\$12,200</b>
Buy 500	Good	0.2	x	\$34,000	\$6,800
	Average	0.5	x	\$15,000	\$7,500
	Poor	0.3	x	-\$10,000	<u>-\$3,000</u>
					<b>\$11,300</b>

**Figure 2-1:** Decision tree (Source, Kay and Edwards, 1999)

The possibilities of each weather condition multiplied by its corresponding net return give the expected value of that strategy. In the case presented here, the strategy with the highest expected value is that of purchasing 400 steers. Although it would be seen as the best in terms of expected value, it does not account for risk attitudes or some other influential factors which can have a bearing on decisions made. For example, with this strategy there is a 0.3 probability of earning \$0, which may cause harm to the business. The option of buying just 300 steers always result in a positive return, but they returns are smaller compared to the positive returns probable from the other two options. The optimal choice for a given individual may not necessarily be the strategy with the highest expected value, relative to the individual's attitude to the possible outcomes, such as making a significant loss.

### **2.3. Farmer Risk Attitudes and Preferences**

Risk attitudes are typically divided into just three categories, risk-neutral, -averse and risk-loving. A risk-neutral person would be expected to choose the strategy with the highest expected value regardless in the variations of possible returns, i.e. choose the option of purchasing 400 steers from the decision tree presented in Figure 2-1. On the other hand, risk-averse individuals exhibit a willingness to accept a lower expected return so as to avoid the opportunity of unfavourable outcomes. In the presented in Figure 2-1, the chance of earning \$0 or making a \$10,000 loss may be unacceptable and the option of purchasing 300 steers although resulting in a lower expected return may be preferable (Kay and Edwards, 1999). However, risk-aversion does not necessarily mean that individuals are not willing to take risks. Rather it means that individuals must be compensated for taking the risk and that the required compensation must increase as the risk and/or the levels of risk-aversion increase.

To be more useful, agricultural models should account for risk and the risk attitudes of farmers. Pannell and Nordblom (1998) recognised the need for models to account for risk and the risk attitudes of farmers to be considered useful; in their report on the effect of risk aversion on whole farm management in Syria, they found significant effects in terms of farming policies related to risk attitudes. Different approaches have been used in describing risk in agriculture: the expected value and utility approaches and models (e.g. Hazell and Norton, 1986; Hardaker, *et al.*, 1991; Rae, 1994; Hardaker *et al.*, 1997), heuristic safety-first approaches (e.g. Roumasset, 1976; Anderson *et al.*, 1977), farmers' risk aversion (e.g. Hazell, 1982; Binswanger, 1980), and the effect of risk on farmers' resources (e.g. Herath *et al.*, 1982). Traditionally, farming systems were modelled with regards to risk attitude, thus assuming decision makers to be either averse or neutral, or generally just assuming risk aversion, using some measure of preference such as subjective expected utility (SEU)

(Hardaker and Lein, 2003). The SEU hypothesis involves breaking down risky decision problems into separate assessments of the decision-maker's beliefs about uncertainty, captured via subjective probabilities, and the decision-maker's preferences for consequences, obtained via a utility function, the two parts are then recombined to select as optimal the decision which yields the highest expected utility or certainty equivalent (CE). Generally, the SEU hypothesis provides the best operational basis for structuring risky choices.

### 2.3.1. Utility and Expected Value

To explain utility and expected value, assuming there are just two possible choices, one with a greater expected value than the other, that choice with the greater expected value is the best. However, if the option with the greater expected value has two possible outcomes, one of great profit as well as one of great loss, and the second possible choice has a lower expected value, with neither of the two potential outcomes resulting in a significant loss, the second possible choice may be preferable to some people which introduces the concept of risk attitudes and utility (Hardaker *et al.*, 1997).

Hardaker *et al.* (1997) used a sample decision problem in which there was a once-only choice to be made between options  $a_1$  and  $a_2$ , with consequences depending on two equally likely uncertain events  $s_1$  and  $s_2$  to explain the economic concept of utility. This is presented in Table 2-1 below.

**Table 2.1:** Economic concept of utility example

$S_i$	$P(S_i)$	$a_1$	$a_2$
$s_1$	0.5	1000	500
$s_2$	0.5	0	500
EMV <sup>1</sup>		500	500

<sup>1</sup>see text for description

A risk averse individual will prefer  $a_2$  to  $a_1$ , whereas a risk preferrer will chose  $a_1$  to  $a_2$ . Ordinarily, any person indifferent to risk would base their choice on the expected monetary value (EMV) therefore portraying indifference between the two options. Assuming there is a progressive reduction of the \$500 payoffs represented by choice  $a_2$ , there would come a point where the risk adverse decision maker is indifferent between options  $a_1$  and  $a_2$ . Presume that the certainty equivalent (CE) for some individual is \$450 in the example above. It can be said that the utility of the risky prospect  $a_1$  is equal to the utility of the \$450 CE for this person. Based on arguments presented above, it can be shown that utility function,  $U$ , exists and exhibits the properties that:

$$U(a_1) \succ U(a_2) \tag{2:6}$$

From equation 2:6, utility function  $U$  exists only if  $a_1$  is preferred ( $\succ$ ) to  $a_2$  and that

the utility of a risky prospect is its expected value (E):

$$U_{(a1)} = E[U_{(a2)}] \quad (2:7)$$

The second property suggests that the utility of the risky prospect  $a_j$  is equal to its expected utility, computed as the probability weighted average of the utilities of the individual consequences, while the first property implies that this utility value is equal to the utility of the CE such that:

$$U_{(a1)} = 0.5U(1000) + 0.5U(0) = U(U_{(a2)}) = U(450) \quad (2:8)$$

### 2.3.2. Assessing Risky Alternatives

According to the subjective expected utility (SEU) hypothesis (Savage, 1954; Anderson *et al.*, 1977) the decision-maker's utility function for outcomes is necessary in order to assess risky prospects. The SEU hypothesis states that the utility or index of relative preference, of a risky prospect is the decision-maker's expected utility for that prospect, i.e. the weighted average of the utilities of outcomes. The index is calculated using the decision-makers utility function to encode preferences for outcomes. Given a choice amongst alternative risky prospects, the hypothesis imply the prospect with the highest expected utility is preferred.

The expected utility of any risky prospect can be converted through the inverse utility function into a CE. Ordering prospects by CE is the same as ordering them by expected utility, i.e. in the order preferred by the decision-maker. Besides, the difference between the CE and the expected value of a risky prospect, referred to as the risk premium (RP) is a measure of the cost of the risk:

$$RP = E - CE \quad (2:9)$$

In the case of a risk-averse decision maker's, RP will be positive and its magnitude will depend on the distribution of outcomes as well as the decision maker's attitude to risk.

As shown thus SEU hypothesis demonstrates how to integrate the two components of utility (preference) and probability (degree of belief) to afford a means of ranking risky prospects, thus enabling risky choices to be rationalised. The utility a person gains from a decision and not just the expected financial return obtained from it are as important in making risk management decision.

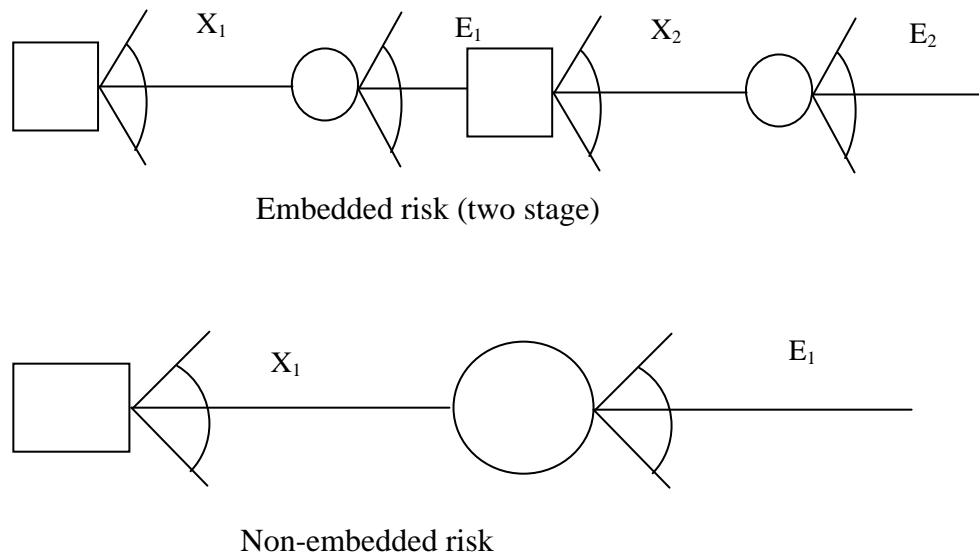
Kingwell (1994) using a model called MUDAS (Model of Uncertain Dryland Agricultural System) looked at the effect of risk attitudes on responses to risk in dryland

farming systems. Under the two price scenarios considered, increased risk aversion shifted resources away from cropping towards the livestock enterprise and changed the tactical management of the farming system. In particular, increased risk aversion reduced the area of crop in favourable weather-years and enabled pasture to be productive thereby supporting more sheep at higher stocking rates. A study by Kingwell *et al.* (1993) explored the importance of considering tactical response in addition to the traditional risk attitude in modelling agricultural systems. They concluded that stochastic models which do not include activities for tactical adjustments miss the benefits of flexibility due to knowledge about uncertain prices and costs (real profit). Inclusion of tactical response options has previously received little attention compared to farmers' risk attitude (Marshall *et al.*, 1997).

Pannell *et al.* (1995) hypothesised that the benefits of including tactical response options in a farm model are often greater than the benefits of including risk aversion. The importance for strategic choice of accounting for the opportunities to tactically respond to outcomes of risk provided by each strategy has attracted attention (Marshall *et al.*, 1997). Regardless of whether farmers are averse to risk, prefer it or are ambivalent about it, they tactically adjust their farming strategies as the outcomes of risk relating to seasonal conditions, prices and other sources of risk become known (Antle, 1983). This is what constitutes embedded risk (Hardaker *et al.*, 1991).

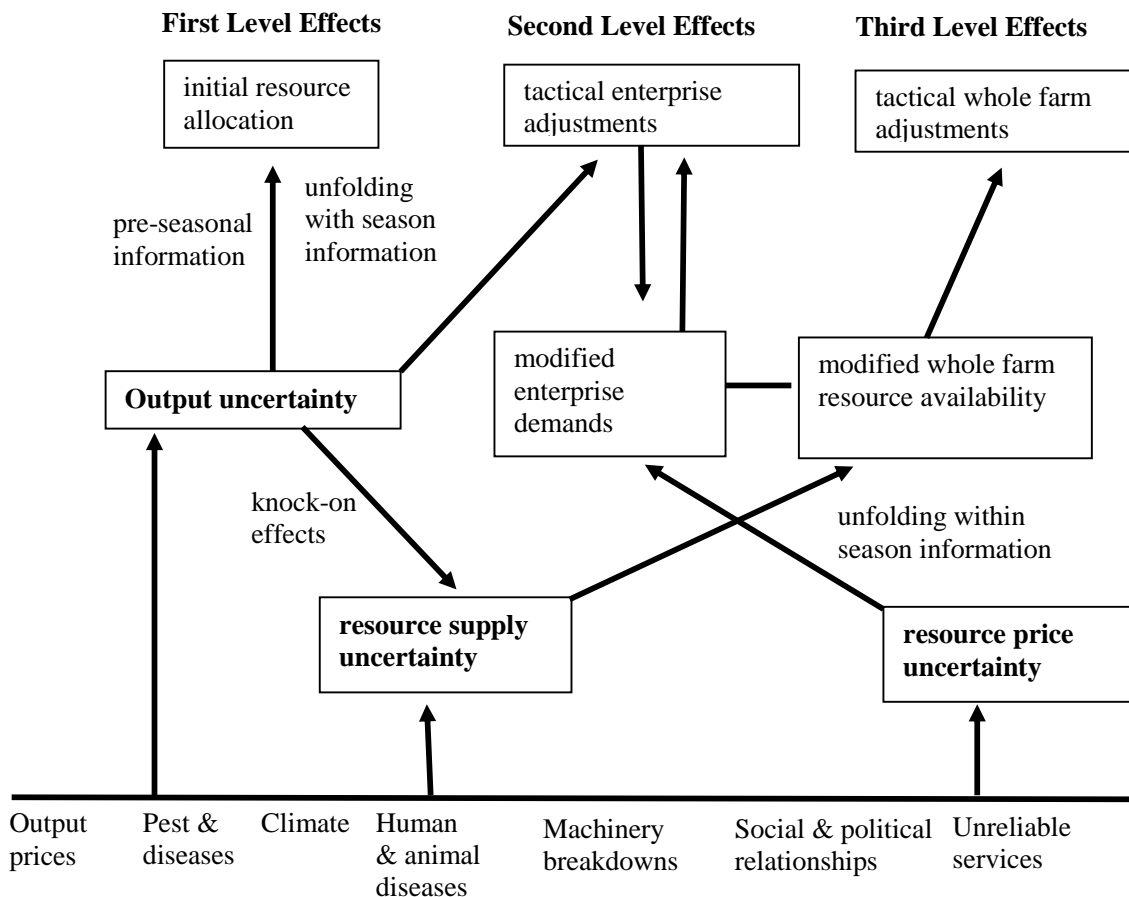
#### **2.4. Embedded Risk**

Evaluation of farmers' risk attitude mostly address non-embedded risk where activities are assumed to have known resource requirements but to yield uncertain returns, as a result of physical yield or output price uncertainty (Dorward, 1999). In many situations, however, farmers face 'embedded risk' (Hardaker *et al.*, 1991), where they have the opportunity to make sequential decisions and adjust the timing and methods of their activities as a season progresses and more information on uncertain events or occurrences becomes available. Embedded risk allows for adjustments to be made to farming operations tactically to suit the conditions as they develop i.e. to make management changes within a season. Figure 2-2 below was obtained from Hardaker *et al.* (1991) to simply illustrate a decision tree notion of options or choices within a season.



**Figure 2-2:** Embedded and non-embedded risk decision tree (Hardaker *et al.*, 1991)

Hardaker *et al.* (1991) argue that modelling farming system considering non-embedded risk is inadequate since it assumes that it is realistic to model a system as if all decisions (e.g.  $X_1$ ) are made initially and then the uncertainty unfolds subsequently in terms of risky consequences (e.g.  $E_1$ ) of the choice taken. In an embedded risk scenario, decisions are segregated into those taken initially (e.g.  $X_1$ ) and those taken at a later stage (e.g.  $X_2$ ) when some information on uncertain events (e.g.  $E_1$ ) have unfolded. Most real decisions about farming systems have the characteristics of the second case where farmers respond tactically as information on uncertain events becomes available. Despite this reality, many mathematical programming models (MP) addressing decision making in agricultural systems have either ignored risk, or have treated it as non-embedded. Hardaker *et al.* (1991) pointed to the complexity of modelling embedded risk as the main cause of this omission. Dorward and Parton (1997) examined how important embedded risk is to complex, diverse and risk prone agriculture. They discussed risk such as uncertain climatic behaviour, pests and diseases as well as output price risk in agriculture. They then described how a farmer could respond to the uncertainty as the season progressed and more information became available as shown in Figure 2-3.



**Figure 2-3:** Tactical responses to uncertainty (Dorward and Parton, 1997)

Pannell *et al.* (1995) hypothesised that the benefits of including tactical response options in a farm model are often greater than the benefits of including risk aversion. This is in line with studies by Kingwell *et al.* (1993) and Marshall *et al.* (1997). Kingwell *et al.* (1993) found that modelling tactical adjustments resulted in the identification of an optimal farming strategy expected to be 20.0% more profitable on average than the strategy that would have been identified considering a non-tactical approach. Modelling risk aversion was found to result in the identification of an optimal strategy that had only 2.0–6.0% higher CE than the strategy that could otherwise have been identified (Kingwell, 1994). Marshall *et al.* (1997) in supporting the hypothesis by Pannell *et al.* (1995) noted that, failing to account for risk aversion would not affect the strategy chosen; however, failing to account for tactical adjustments would lead to the choice of a sub-optimal strategy. Their research investigated the optimal reticulation strategy in relation to the storage of irrigation water. Alternative strategies were modelled assuming farmers to be either risk-neutral or averse (within bounds). The strategy determined to be optimal under the assumptions above was then compared against the optimal solution when the model allowed for tactical adjustments. They showed

that failing to account for tactical responses would lead to the choice of a sub-optimal strategy, costing the farmer about \$3,100 Australian dollars in present value terms. In contrast, failing to account for risk aversion would not affect the strategy chosen. This confirms the observation made by Pannell *et al.* (1995) that, there are potential dangers in ignoring the benefits and costs of tactical choices allowed by the strategies being evaluated. To confirm the importance of including tactical response options in farm models, Marshall *et al.* (1997) emphasised the need to undertake further studies. This study will contribute to the critically needed information on the importance of including tactical response options in farm models.

Antle (1983) observed that seasonal variation affects both risk-averse and risk-neutral farmers' decision making. Risk-averse farmers adopt long-term farming strategies which show preference for lower but stable income. Kingwell *et al.* (1993) noted that most farmers are risk-averse. Both risk-averse and risk-neutral farmers make tactical adjustments to their farming strategies in response to short-term seasonal conditions. There are potentially two facets to the value of climatic information used to make these adjustments. Firstly, they allow for improvement in expected income for all farmers and secondly, they can reduce the cost of risk for farmers who are risk-averse (Kingwell *et al.*, 1993).

Agricultural economists have invested more resources in studies of the longer-term implications of seasonal variation for risk-averse farmers with much less emphasis going into short-term (within season) tactical decisions (Kingwell *et al.*, 1993). Mjelde *et al.* (1989) noted that even where models allow for seasonal variation and risk-aversion, the common practice has been to ignore the potential for tactical adjustments to the farming strategy according to short-term conditions. The result is an underestimation of the profitability of some strategies (Kingwell *et al.*, 1993) and inconsistent production function parameter estimates (Antle, 1983; Antle and Hatchett, 1986).

## **2.5. Risk sources and management strategies in dryland pastoral systems in New Zealand**

Martin (1994, 1996) identified a range of risk sources and corresponding management strategies in a wide variety of farming systems in New Zealand, including both irrigated and dryland pastoral production systems. Results from Martin's 1994 survey-based study of pastoral farmers ranked change in products prices as being the most important risk source. Changes in world economic and political situations, changes in New Zealand economic situation, changes in input costs, rainfall variability, pests and diseases (for deer farmers), changes in producer board policies (for dairy and deer farmers), changes in government laws

and policies (for deer farmers) and risks associated with accidents or health problems were the other risk sources identified by farmers in the pastoral sector as being important. A previous survey-based study involving dryland sheep farmers on the Canterbury Plains by Harris *et al.* (1991) identified the three most important risk sources as rainfall, livestock/product prices, and the world economic and political situation.

All the three groups of pastoral farmers surveyed by Martin (1994) noted that routine spraying and drenching and maintaining feed reserves were the most important risk management responses. Low debt level was considered important in risk management as was managing capital spending and maintaining short and long-term flexibility in farming operations. Additionally, sheep, beef cattle and deer farmers utilised market information, spreading sales and investing in more than one enterprise as important risk management strategies. Harris *et al.* (1991) singled out use of animal feed reserve to be the most important risk management strategy, followed by production flexibility, market information and pacing of investments and expansion.

Gray *et al.* (2008) classified risk management strategies into three broad categories; those targeted to feed supply, feed demand and marketing decisions. They went further to suggest farmers need to design their systems to cope with these production and market risks. In coping with production risk, farmers have to increase feed supply over the summer and autumn, and target to transfer feed from the spring to the summer-autumn and winter periods, significantly reduce feed demand over the summer-autumn period, protect capital stock liveweightss and ensure adequate pasture cover levels at lambing.

To eradicate and/or reduce the negative impact of market risk, Gray *et al.* (2008) suggested that farmers should: aim for the sale of stock in periods when most other farmers are not selling, target to finish the bulk of stock rather than sell stores, target to purchase stock at times when other farmers are not buying, and generate adequate feed reserves that can be used to delay stock sales in drought until such a time as the markets improves.

They identified four main tactical adjustments to cope with variation in feed supply within years. These were a need for a sophisticated monitoring system that quickly identifies problems or opportunities, a plan with clear targets that monitored data can be compared against, a historical database of climatic and farm performance data, and a broad set of contingency plans and associated decision rules to determine the best option to implement for the existing conditions.

Other risk management strategies have been suggested by different authors such as geographical dispersion by Boggess *et al.* (1985) where farmers buy land in areas where

summer production circumstances are good. This strategy would be expected to reduce market risk but it may come with increased financial risk (Gray *et al.*, 2008). The study by Harvie (1989) identified destocking as the most used strategy in drought with farmers preferring to dispose of stock instead of incurring the cost of supplementing animals or grazing them off. Other options used in response to dry conditions have been summarised by MAFPolicy (1992) as rotational grazing, maintenance of buffer stock, wintering dry ewes and reducing replacement numbers to match feed supply.

Bywater *et al.* (2011) identified the possibility of rainfall decreasing during late spring and early summer to a point where grass growth ceases as a major source of risk in dryland pastoral systems and suggested that important variables in managing this risk are fast lamb growth rate and the flexibility to change feed demand (by destocking) or feed supply (by feeding supplements) rapidly when conditions dry out. Lamb growth rate is important because the risk of dry conditions and reduced feed supply increases as the season progresses and faster growing lambs have a higher chance of being drafted before conditions change.

A key variable in lamb growth rate is feed quality. Use of alternative pasture species has been identified as having potential to improve the profitability of hill country farms by Korte and Rhodes (1993) so long as the improved pasture production and quality can be captured by livestock in a profitable way. Fraser *et al.* (1999) also investigated improved pasture species under dryland conditions and showed an increase in lamb growth rate and rate of drafting compared with conventional pastures but noted a lower persistence of the improved pasture species. Other studies that placed emphasis on high quality feed particularly during the pre-weaning period were those by Kinnell (1993) and Gray *et al.* (2008). However, unlike this study they did not consider use of alternative pasture species to achieve high quality pasture during lactation. The study by Grigg *et al.* (2008) showed that managing subterranean clover to maximise yields increased subterranean clover content to 40–60% of sward dry matter content over spring. This resulted in increased lamb growth rates from 258-350g head<sup>-1</sup>day<sup>-1</sup>, lamb weaning weights from 29.6-40.0 kg and lambing % from 108-140% through improved ewe weaning weights. The benefits were as a result of more than 7 years use of a range of strategies including application of fertiliser and lime, property sub-division and subsequent improvement, building up a subterranean clover seed bank, controlled grazing of seedlings in autumn, spelling for two months pre-set stocking, and managing spring seed head development.

Avery *et al.* (2008) proposed use of lucerne in dryland systems allowing farmers to grow and finish stock faster over late spring, summer and autumn compared to traditional

pastures. The advantage they noted was that lucerne produced higher quality feed as well as a greater quantity over drier months and is more persistent in dryland environments. By extension the downside in use of alternative pasture is the limited feed supply (reduced production) over winter which Avery *et al.* (2008) addressed through the use of Omaka forage barley and annual ryegrass. Financial benefits of the change from a conventional feed supply system reported by these authors have been dramatic.

The field trial carried out by Bywater *et al.* (2010) to investigate and demonstrate key aspects of high performance sheep systems in dryland environments had an emphasis on high pasture quality and utilisation, use of breeding ewes selected for low bodyweight and high fecundity (high efficiency ewes; Rutherford *et al.*, 2003), and inclusion of flexible management strategies to allow rapid destocking as soon as conditions became dry. The trial considered most of the risk management strategies and flexibilities discussed above.

The study reported in this thesis aims to extend the trial of Bywater *et al.* (2010) to further evaluate risk management strategies and flexibilities by varying stocking rate, pasture combinations, flexibility options and soil moisture levels used to initiate destocking/sale response. Risk management strategies considered in this study include:

- Early lambing of older ewes to allow early weaning and sale
- Use of 2 yr old cattle (strategies 2, 4, and 6 in this study) to assist in maintaining low residuals in sheep pastures and as a readily sellable stock class
- ‘2 yr’ ewes instead of cattle (strategies 3, 5, and 7 in this study) with majority lambed early
- A paddock of lucerne (strategies 1, 2, 3 and 4) in grass dominated systems to extend feed supply in dry conditions
- All stock (in all strategies) sold before the end of the year
- Use of supplements and grains when absolutely necessary

## **2.6. Managing Grazing Systems**

Managing grazing systems is complicated by the need to balance the nutritional requirement of different classes of livestock with a feed supply that fluctuates in quality and quantity between years (Finlayson *et al.*, 1995). This complexity and the uncertainty that occurs in the decision making are the major features that emphasise the importance of a systems approach to analysing agricultural systems. The systems approach was summarised by Doyle (1990) as the whole being more than the sum of the parts. Accordingly, systems theory is primarily concerned with the systematic study of interactions between the different factors (subsystems) that make up the whole. The initial stages of systems theory

development linked it to the use of models (Doyle, 1990).

### **2.6.1. Modelling Grazing Systems**

Many production processes can be usefully considered from a systems viewpoint. This is because many such processes are intrinsically linked and therefore must be viewed in a holistic manner if they are to be properly understood and controlled (Doyle, 1990). For example, most interactions in farming systems are of complex biological nature, but important links between processes are also involved. There are various reasons given for using a systems approach in analysing complex agricultural systems. Doyle (1990) and Dent (1975) categorised the reasons into three. These were (i) the impracticability or impossibility of studying the real system; especially where research is concerned with designing new systems, (ii) cost and time limitations which make experimentation not feasible, and (iii) the scenario where experimental procedures lead to a disturbance in the real system to such points and/or levels that the observation relate to something artificial.

A model must be developed based on a clear purpose with an intention of solving a well defined problem. Clarity in model description assists the users to evaluate its usefulness in addressing the question under consideration (Shannon, 1975; Hannon and Ruth, 1997). There are many reasons to try to model an agricultural system, including assisting farmers in decision making, to try and predict the effect of a policy change, or to evaluate the value of new technology or change in a production system such as building an irrigation scheme (Swinton and Black, 2000).

Agricultural systems models are diverse in focus (i.e. ranging from sub-molecular systems to global agro-climatic systems), in character (i.e. range from the biophysics of plant nutrient transfer across root hair to the sociology of transhumant livestock herders), and in duration i.e., range from hours for feed digestion or photosynthesis to centuries for soil erosion (Doyle, 1990; Swinton and Black, 2000). Keating and McCown (2001) recognised two important components in agricultural systems: the biophysical which they considered as constituting the production system of crops, pasture, animals, soil and climate together with certain physical inputs and outputs, and the management system, made up of people's values, goals, knowledge, resources, opportunities, and decision making. Utilising these constructs, they defined six types of farming systems analysis and intervention that have evolved over a long period: (i) economic decision analysis, (ii) dynamic simulation of production processes, (iii) economic analysis linked to biophysical simulation, (iv) decision support systems, (v) expert systems, and (vi) simulation aided discussion about management in an action research focus.

## 2.6.2. Models Classification

Swinton and Black (2000) classified system models as analogue, iconic, or symbolic. Iconic models are visual—that is, physical representation of a system. In modelling agricultural systems, iconic and symbolic models are more commonly used compared to the analogue models. They often take the form of a flow chart or picture demonstrating the inputs and outputs from an agricultural system, and the interactions and transfers that take place between components of the whole system. Symbolic models are mathematical by nature and use equations to represent interaction in a system (Ford, 1999; Sterman, 2000).

Mathematical models in general have various benefits including: (i) allowing representation of complex characteristics of a system using detailed equations, (ii) allowing representation of stochastic or random processes, and (iii) allowing the study of a system with both precision and replication (Swinton and Black, 2000). Models of agricultural systems can further be classified spatially, temporally, hierarchically or by subject matter (Fresco, 1994; Rhoades, 1998). Models can also be static or dynamic, mathematical or physical, stochastic or deterministic. Another classification divides models into those that optimise versus those that simulate. According to Peart and Curry (1998) and Swinton and Black (2000), there are three types of mathematical models; econometric, optimisation, and simulation models. These three types of mathematical model serve four general purposes (Schoemaker, 1982) which are description, prediction, postdiction and prescription. Descriptive models are used to characterise the system to model. Their performance in turn, allows modellers to evaluate whether they have adequately described the key systems aspects. Predictive models are utilised to project future modelled system behaviour. Postdictive models are used in evaluating and analysing past system performance. Prescriptive models offer guidance on how a system should be managed to meet a specific goal. Depending on the study objective, many agricultural models serve more than one purpose (Schoemaker, 1982).

Econometric models are used to test specific hypothesis and/or to estimate parameters for other types of models. Econometrics is the measurement of economic relations, and it generally involves statistical analysis of economic data (Schoemaker, 1982). The main weakness in econometric models is the explicit assumptions of the underlying economic theory on which they draw; assumptions about the rationality of human behaviour, about the availability of information that real decision makers do not have, and about equilibrium. Econometrics also contain some inherent statistical limitations. The regression procedures used to estimate parameters yield unbiased estimates only under certain conditions (Sterman, 1991). The other problem with econometrics is that it fails to distinguish between correlations

and casual relationships. Simulation models should portray the casual relationship in a system if they are to mimic its behaviour, especially its expected behaviour in new situations. But the statistical techniques used to estimate parameters in econometric models do not prove whether a relationship is casual. They only reveal the degree of past correlation between the variables, which may change or shift as the system evolves (Shannon, 1975; Swinton and Black, 2000).

Normally, the output of an optimisation model is a statement of the best way to accomplish a specific goal. Optimisation models do not inform what will happen in a certain situation; they are normative or prescriptive models (Doyle, 1990). Generally, many optimisation models have a variety of limitations and problems including difficulties specifying the objective function, unrealistic linearity and lack of dynamics and feedback as noted by Sterman (1991). The objective function embodies values and preferences, but may fail to identify which values and whose preferences are to be incorporated into the objective function.

Simulation models are developed with the intent of accurately describing a system at a given level of operation. Their main purpose is to mimic the real system so that its behaviour can be studied (Shannon, 1975). Unlike optimisation models, simulation models do not calculate what should be done to reach a particular goal, but rather to clarify what would happen in a given situation. Simulation models gained popularity due to the limited ability of statistical and optimisation models to describe the complex biological and economic processes underlying a system (Doyle, 1990; Keating and McCown, 2001). More recently simulation models have been used (embedded) in optimisation routines that allow for identification of ‘best’ strategies (e.g. Savage and Lewis, 2005). There are many different simulation techniques, including stochastic modelling, system dynamics, and discrete simulation. Irrespective of differences amongst the simulation techniques, they all share a common modelling approach.

The purpose of simulation models may be forecasting by predicting how systems might behave in the future under assumed conditions, or evaluating the effects of new policy on the behaviour of the system. Simulation models mainly answer ‘what if’ questions from a systems point of view. They can be considered as “what if” tools and in most cases the “what if” information is more important compared to the knowledge of the optimal decision (Pannell *et al.*, 1995). These models are particularly helpful in the study of processes in which time is critical—that is, when actions in one period in time have implications on outcomes in future. This explicitly explains the importance of adopting simulation models in this study. In managing embedded risk, a decision made on a certain point of the production season affects

future decisions and outcomes. Agricultural processes such as animal and pasture growth, and grazing systems management which fall under this category can be difficult to conduct at field experiment level, as time and financial constraints prevent data being collected over sufficient periods of time (Doyle, 1990). In such cases, computer models are often utilised to simulate the processes over a period of seasons or years, and to generate data which is then used as an input for other types of models. In most cases, available field data from the system being modelled (or a similar comparable system elsewhere) is used in validating the model. It is important to note that simulation models are not designed to produce solutions for use in policy or decision making; rather, their outputs show what would happen to a system given certain circumstances.

Biological processes are by nature dynamic and values taken by variables in biological process, including the parameters describing interactions between variables may change over time, usually interactively. Process outcomes are not wholly predictable, especially where variables interact in nonlinear ways. An appropriate, integrated bio-economic model should capture the dynamic nature of various biological processes involved at the same time allowing for dynamic feedback effects between human decisions, biological responses, and the range of potential future decisions (Hannon and Ruth, 1997; Ford, 1999; Sterman, 2000). There are three main components in a grazing system, namely the plant (pasture), animal and management (humans). The key biological processes in a grazing system relate not only to plant and animal growth, soil physical characteristics and nutrient flows and balances as they respond to the physical environment and human activity but also include interspecies interactions, competition and feedback effects from one sub-system to the other— including the economic and social decision making environment (Sterman, 2000).

## **2.7. Grazing System Models**

### **2.7.1. Pasture Growth Sub-model**

Models of grazed pasture have previously been reviewed by Hanson *et al.* (1985) and Herrero *et al.* (1997). These models range from simple biomass models to study particular interactions (Noy-Meir, 1975; Hirata *et al.*, 1992; Woodward *et al.*, 1995) through complex conceptual-mathematical systems such as the models by Sheehy *et al.* (1980), Johnson and Parsons (1985), and Schwinning and Parsons (1996) to computer simulation models with large numbers of parameters and state variables (McCall 1984; Hanson *et al.*, 1988; Blackburn and Kothmann 1989; Hunt *et al.*, 1991; Seligman *et al.*, 1992; Mohtar *et al.*, 1994; Barioni, 1997). Some grazing system models are system-specific, for example those that consider arid (Hacker *et al.*, 1991) or nitrogen-limited (van de Ven, 1992) pastoral systems. In

grazing systems, it is desirable to have a model that can describe sward growth under different conditions by adjusting parameter values, rather than a set of empirical equations that change form as environmental conditions change (Cacho, 1993).

Certain biological processes are common to most pasture models. These include: photosynthesis, assimilate partitioning, growth, defoliation, death and decomposition. Bywater *et al.* (1999) developed a mechanistic pasture growth model based on the methodology described by Woodward (1998) and Woodward *et al.* (1998). The Bywater *et al.* (1999) mechanistic pasture growth model was used in this study. The model parameters represent the differences in sward growth for pasture species by the values of model parameters rather than differences in the model structure. Consequently, model parameters must be determined for each pasture species that the model is used to simulate. The model has previously been used in simulating growth and feed intake of grazing sheep (Bywater *et al.* , 1999) using parameters for perennial ryegrass, white and red clover, tall fescue and chicory. In addition, pasture plants considered for simulations in this study are cocksfoot, annual ryegrass and lucerne. The methods of obtaining the model parameters for these additional species are described in Chapter 4.

### **2.7.2. Animal Growth and Composition Sub-model**

A number of approaches to predict animal growth have been reported, the earliest and most common method is the single equation model or the growth curve (Gompertz, 1825; Brody, 1945; Verhulst, 1838). These equations are empirical which limits their use in predictive models of growth in beef cattle. More detailed growth models have been reported for beef cattle (Loewer *et al.*, 1983; Sanders and Cartwright, 1979), sheep (Marshall *et al.*, 1976) and swine (Whittemore and Fawcett, 1979). These models incorporate additional factors describing growth, which improves their utility. However, these models do not represent biological processes that are determinants of growth. Their equations are defined for the most part on an empirical basis making their efficacy uncertain when extended to new situations (Oltjen *et al.*, 1985). Explicit representation of factors such as animal's genetic background and nutritional history is important as these affect performance (Sainz *et al.*, 1995). Baldwin and Black (1979) and Burleigh (1980) developed models representing fundamental processes that regulate growth which were primarily developed for research purposes making them too complex to operate as routine predictors of growth (Oltjen *et al.*, 1985). Oltjen *et al.* (1986b) described a dynamic post-weaning beef growth and composition model (Davis Growth Model; DGM) based on fundamental biological concepts of hyperplasia and hypertrophy applied at the whole animal level, and simulates both body weight gain and

composition. The DGM was chosen to predict beef cattle performance in New Zealand grazing conditions and is discussed in details in Chapter 5. It was incorporated in LincFarm model to simulate beef growth and composition.

## **2.8. Choice of LincFarm simulation system**

There are a number of grazing systems models available around the world for different animal enterprises. Within New Zealand there are two livestock system simulation models potentially available for this study; Stockpol (McCall, 1984; Marshall *et al.*, 1991; Webby *et al.*, 1995) which is available commercially as Farmax (FARMAX Ltd, 2007) and LincFarm (Bywater, *et al.*, 1999, Cacho and Bywater, 1994, Cacho, *et al.*, 1995, Finlayson, *et al.*, 1995). Both models were evaluated for use in the analysis and LincFarm was chosen for three main reasons.

LincFarm has the ability to subdivide the farm into paddocks and use them to make blocks in which different animal, pasture and management aspects can be applied. Similarly, animals can be grouped in mobs where different management can be applied, and output data can be obtained for a specific mob implying that different management aspects can be tested on different mobs on the same farm. Farmax is not so flexible in the animal, pasture and management aspects and assumes that mobs defined on a farm are distributed across all the defined blocks.

LincFarm has the capacity to run an analysis for as many years as desired by the user, as long as relevant weather data are available. Farmax runs a 12 months cycle and balances ending and starting pasture mass making it very difficult to run a 20 years analysis with the state of the system carried forward from one year to the next, as required in this study.

LincFarm includes a limited number of conditional decisions in the management calendar. This means that decisions made at a particular point in time in the simulation can be conditional on the situation existing at that time rather than being fixed at the start of the simulation. For example, hay making can be conditional on current pasture mass and hay feeding can be conditional on the condition of the animals. While the extent of conditional decision making needs to be expanded for the current study (see chapter 6), the fact that this is possible is essential for the analysis to be undertaken.

Other advantages to LincFarm are that it has greater flexibility to determine the output from the model, which is important where a detailed analysis of the reasons behind an improved enterprise performance is required. For example in this study pasture quality and utilization factors were considered in evaluating and discussing the factors behind differences in productivity and profitability of alternative risk management strategies. Also, the source

code was readily available for the necessary extensions required in the study.

## **2.9. Model Evaluation**

Model evaluation in the modelling process is an essential phase as it indicates a model's level of precision and accuracy (Tedeschi, 2006). Johnson (2001) noted that the term evaluation is proposed to indicate model adequacy based on pre-established criteria of model performance such as functionality, accuracy and precision for its intended purposes. Accuracy addresses the measure of how closely model output values are to the true values (observed values) while precision measures how close individual model output values are—that is, how far one output varies from the next one. Thus accuracy is the model's ability to predict the right values while precision is the capability of the model to predict similar values consistently. Generally, the evaluation phase determines whether a model is an adequate representation for the process which it is designed to simulate rather than establishing the truth of the model in any absolute sense. Furthermore, the validity of a mathematical model cannot be proven, except determining whether it is appropriate for its intended purpose under given conditions (Tedeschi, 2006).

There are various methodologies employed in model evaluation including analysis of fitting errors described in Mitchell (1997) and Mitchell and Sheehy (1997) where deviations (model-predicted minus measured values) are plotted against the observed values and the percentage of points lying within an acceptable range (envelope) is used as a criterion of model accuracy. The difference between model-predicted and measured values provides adequate information on the extent to which the model fails to simulate the system. Another method of model evaluation is the concordance correlation coefficient which is described in Tedeschi (2006). This methodology tests whether the model-predicted values are simultaneously precise and accurate across a range and that the values are tightly amalgamated along the  $y=x$  (unity) line through the origin. A third evaluation method referred to as diverse deviation measurements is described in details in Tedeschi (2006). This includes the mean bias (MB) which is considered as notably the oldest model evaluation method. Its calculation is based on the mean difference between observed and model-predicted values (Cochran and Cox, 1957). Other methods in diverse deviation measurements include resistant coefficient of determination; this uses medians instead of means resulting in a coefficient that is more resistant to outliers or extreme data points, modelling efficiency, and coefficient of model determination (CD) which is the ratio of the total variance of observed data to the square of the difference between model-predicted and mean of the observed data.

The mean square error of prediction (MSEP) is the most common and recommended

method to measure the predictive accuracy of a model. A detailed discussion of the ordinary least squares technique to evaluate linear models using mean square error (MSE) and MSEP is presented in Bibby and Toutenburg (1977). The MSE assesses the precision of the fitted linear regression using the difference between observed values and regression-predicted values. Conversely, MSEP consists of the difference between observed values and model-predicted values rather than regression-predicted values.

Kobayashi and Us Salam (2000) consider the strengths and weaknesses of utilising linear regression analysis methodology in model evaluation in comparison to use of deviation based methodologies. They observed that assessment of model accuracy is done by comparing model output ( $x$ ) and corresponding measured ( $y$ ) values and is usually done through statistical approaches to determine the correlation between  $x$  and  $y$  by producing a correlation coefficient ( $r$ ) describing the degree of linear association between two variables. Linear regression of  $y$  on  $x$  tests whether the intercept ( $a$ ) is or near zero and the slope ( $b$ ) is or near one. The  $r$  is also used to demonstrate how good the model is at predicting the data. Statistical testing of the  $r$  and  $b$  and confidence intervals for these values can be determined (Mayer *et al.*, 1994). This approach is commonly used in fitting empirical model output to field data (Wallach and Goffinet, 1989). However, if the data-set used in fitting and testing a model is the same there exists non-independence of residuals which makes regressing observed values on model-predicted ones inapplicable in such circumstances (Garcia *et al.*, 2008). Similarly when the main objective is comparing mechanistic model predictions with field data, regression is not ideal (Kobayashi and Us Salam, 2000) because in such scenarios the main focus is comparing model's output with the field data rather than fitting the predictions to the data. Considering that  $y$  represents the data and  $x$  the simulated model output, then  $y$  is the sum of the true mean ( $\mu$ ) and the random error ( $\epsilon$ ) associated with the measurement— that is:

$$y = \mu + \epsilon \quad (2:10)$$

When  $y$  is regressed onto  $x$ , a linear relationship is assumed between  $x$  and  $\mu$ :

$$y = bx + a \quad (2:11)$$

where  $b$  is the slope and  $a$  is the  $y$  intercept of the regression line. Then in assessing the “accuracy” of the model in predicting the data the null hypothesis ( $H_O$ ) and the corresponding alternative hypothesis ( $H_A$ ) are:

$$H_O : a = 0 \text{ and } b = 1 \text{ so that } \mu = x \quad (2:12)$$

$$H_A : a \neq 0 \text{ and } b \neq 1 \text{ so that } \mu = bx + a \quad (2:13)$$

This approach contrasts with a direct comparison of  $x$  and  $y$  since  $y$  is still assumed to be the sum of the  $\mu$  and  $\varepsilon$  associated with the data measurement (see equation 2:10). However, in a direct comparison, the null hypothesis is that  $\mu$  equals  $x$  which means that the difference between predicted and observed values is only contributed by the measurement error. In such situation then:

$$H_O : \mu = x \quad (2:14)$$

$$H_A : \mu \neq 0 \quad (2:15)$$

Both the null hypothesis (equation 2:12) and the alternative hypothesis (equation 2:13) imply a linear relationship between  $\mu$  and  $x$  under linear regression approach. This however stands true for the  $H_O$  but not for the  $H_A$  since there may be a curvilinear or discontinuous relationship between the measured and the model values. Thus it is evident that, in linear regression analysis, the variance of the residuals is constant throughout the range of fitted values of  $y$  (Petrie and Watson, 2006). In comparing the model predicted and measured values, it is essential to note that the nature of the relationship for the  $H_A$  is of less importance than whether the simulated values are equal to the true mean (Kobayashi and Us Salam, 2000) as shown in equations 2:13 and 2:14. This allows a direct comparison between  $x$  and  $y$  (via  $\mu$ ) without constraining it to a linear relationship. Deviations; mean bias (MB) and mean square error of prediction (MSEP) (Tedeschi, 2006) or mean squared deviation (MSD) (Kobayashi and Us Salam, 2000) are appropriate methods in such situations. The MSD is a measure of the predictive accuracy and precision of the model. Model evaluation methods described in Kobayashi and Us Salam (2000), which are based on MSD and its components, were utilised in this study in evaluating beef growth and composition, and the mechanistic pasture model adopted.

The deviation ( $d$ ) between  $x$  and  $y$  is calculated as follows:

$$d = x - y \quad (2:16)$$

When there are  $n$  data points for comparison this is most commonly combined into the root mean square deviation (RMSD):

$$RMSD = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - y_i)^2} \quad (2:17)$$

The RMSD can also be expressed as mean squared deviation (MSD) calculated as:

$$\text{MSD} = \frac{1}{n} \sum_{i=1}^n (x_i - y_i)^2 \quad (2:18)$$

where  $x_i$  and  $y_i$  are the simulated and measured values, respectively, for the  $i^{\text{th}}$  data point. Since MSD is the deviation around the line of unity ( $x=y$ ) in a plot of model output and data, then the lower it is the closer the simulation is to the data. The MSD is partitioned into components representing the squared deviation (SB) and mean squared variation (MSV) as follows:

$$\text{MSD} = \text{SB} + \text{MSV} \quad (2:19)$$

where:

$$\text{SB} = (\bar{x} - \bar{y})^2 \quad (2:20)$$

and:

$$\text{MSV} = \frac{1}{n} \sum_{i=1}^n \left[ (x_i - \bar{x}) - (y_i - \bar{y}) \right]^2 \quad (2:21)$$

Terms  $\bar{x}$  and  $\bar{y}$  are the means of  $x_i$  and  $y_i$  ( $i=1, 2, \dots, n$ ) respectively

MSV was further partitioned into two components consisting of the difference in standard deviations of the simulation ( $\text{SD}_s$ ) and of the measurement ( $\text{SD}_m$ ), and a correlation coefficient between the two and can be re-written as:

$$\text{MSV} = (\text{SD}_s - \text{SD}_m)^2 + 2\text{SD}_s\text{SD}_m(1-r) \quad (2:22)$$

where  $r$  is the correlation coefficient between  $\text{SD}_s$  and  $\text{SD}_m$

The components  $(\text{SD}_s - \text{SD}_m)^2$  and  $2\text{SD}_s\text{SD}_m(1-r)$  provide different information about the model. The former denotes the difference in the magnitude of fluctuation between the simulation and measurement (SDSD) while the latter denotes the lack of positive correlation weighted by the standard deviations (LCS). Thus,

$$\text{SDSD} = (\text{SD}_s - \text{SD}_m)^2 \quad (2:23)$$

and:

$$\text{LCS} = 2\text{SD}_s\text{SD}_m(1-r) \quad (2:24)$$

A larger SDSD indicates that the model failed to simulate the magnitude of fluctuation among the  $n$  observations while a bigger LCS means the model failed to simulate the pattern

of the fluctuation across the n measurements. Model evaluation methodology described in Kobayashi and Us Salam (2000) was used in evaluation of suitability of using the plant growth (Chapter 4), and beef growth and composition (Chapter 5) models used in this study.

Chapter 3 presents a description of the LincFarm model which was extended and used in evaluating alternative risk management strategies in this study.

## CHAPTER 3

### The LincFarm Simulation Model

#### 3.0. Introduction

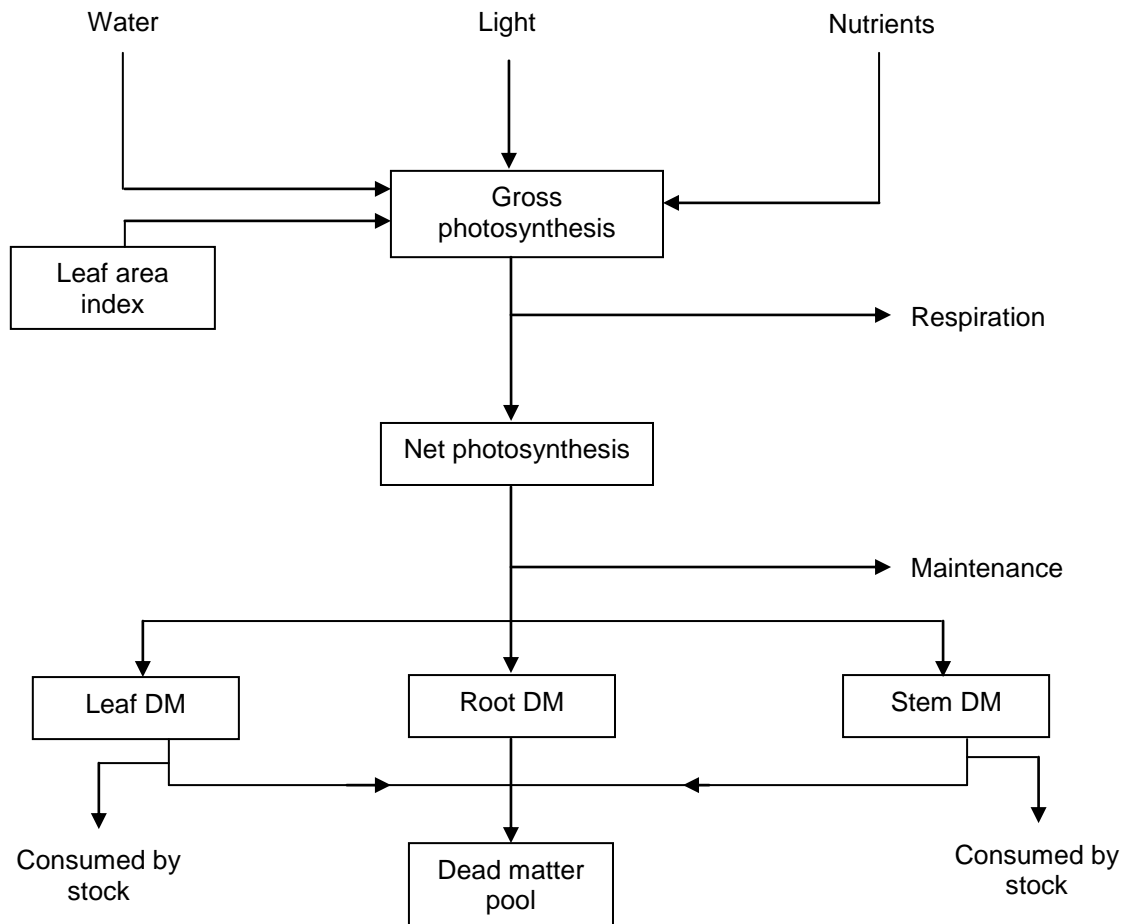
This chapter describes the design and working of the LincFarm grazing sheep system simulation model used as a basis for evaluating alternative policies and risk management responses within high performance dryland sheep systems. The model has been developed over several years and is described by Bywater *et al.* (1999), Cacho and Bywater (1994), Cacho *et al.* (1995) and Finlayson *et al.* (1995). It contains three main components; pasture and animal models, and farm management components.

Several extensions to the existing model have been developed for the current analysis and these are described in subsequent chapters. This chapter describes the model as it was prior to the commencement of this study.

#### 3.1. Pasture Growth Model

Bywater *et al.* (1999) developed a mechanistic pasture growth model based on the methodology described by Woodward (1998) and Woodward *et al.* (1998). The main advantage in the use of this methodology compared to other more theoretical models is that, the resultant model isolates site data from plant and/or canopy characteristics and uses an approximation for estimating photosynthesis rather than integrating photosynthesis over time and depth in the canopy. Some aspects of the Woodward (1998) and Woodward *et al.* (1998), such as lack of explicit incorporation of the effects of temperature and the need to develop further the water relations in terms of estimating soil water level (especially under irrigation) relative to pasture growth were added by Bywater *et al.* (1999) in developing a mechanistic pasture growth model for incorporation in the LincFarm model to replace an empirical pasture growth equation described by Cacho (1993). The resulting model (Bywater *et al.*, 1999) is climate driven and predicts pasture growth on daily time step basis. Figure 3-1 obtained from Doyle *et al.* (1989) summarises the mechanistic pasture growth model.

In redeveloping the Woodward (1998) and Woodward *et al.* (1998) model, Bywater *et al.* (1999) separated the pasture growth model into growth, site dependent, and site and growth interaction sub-models. There were five growth sub-models namely photosynthesis, growth, reproduction, specific leaf area and assimilate partitioning. The site dependent model had two sub-models namely radiation and soil moisture while site and growth interactions had water stress and light capture sub-models.



**Figure 3-1:** Diagrammatic representation of the mechanistic pasture growth model

### 3.1.1. Growth Sub-models

This section describes the existing model of Bywater *et al.* (1999); amendments and extensions to the model for this study are described in preceding Chapter 4.

#### *Photosynthesis*

The model estimates the gross daily photosynthesis of a canopy by the solving the equation:

$$P_d = P_d^g C_{LAI} \quad (3:1)$$

where:

$$P_d^g = \frac{A}{K} + \frac{B}{2K} \quad (3:2)$$

and:

$$C_{LAI} = 1 - e^{-K_{LAI}} \quad (3:3)$$

$P_d^g$  is the potential daily gross canopy photosynthesis ( $\text{mg}[\text{CO}_2] \text{ m}^{-2}$ ) while  $C_{\text{LAI}}$  represents the amount of light captured by the canopy. The parameter  $\kappa$  represents the extinction coefficient of the canopy and LAI (see equation 3:9) is the leaf area index of the canopy defined as the leaf area per unit ground area.

A and B are daily parameters and are dependent on the day and the amount of sunshine hours in the day:

$$A = h p_1 \left( \kappa J_{o,d} \right) + h_{o,s} p_1 \left( \kappa J_{o,s} \right) \quad (3:4)$$

$$B = h_{o,s} \left[ p_1 \left( \kappa J_{o,s} + \kappa J_{o,d} \right) - p_1 \left( \kappa J_{o,s} \right) - p_1 \left( \kappa J_{o,d} \right) \right] \quad (3:5)$$

h is the number of hours of sunlight within a day and  $h_{o,s}$  and  $h_{o,d}$  are the number of hours of direct sunlight and diffuse sunlight respectively.  $J_{o,d}$  and  $J_{o,s}$  are direct and diffuse irradiance respectively given in watts per metre squared ( $\text{W m}^{-2}$ ). Detailed description of methods used in estimating the h, and  $J_0$  and their components are presented in section 3.1.3 below.  $P_1$  is a function of irradiance such that:

$$P_1 J_1 = \frac{1}{2\theta} \left\{ \alpha J_1 + P_{\max} - \sqrt{(\alpha J_1 + P_{\max})^2 - 4\theta \alpha J_1 P_{\max}} \right\} \quad (3:6)$$

where  $P_1(J_1)$  is the gross leaf photosynthesis at any given light level ( $\text{mg}[\text{CO}_2] \text{ m}^{-2}$ ),  $\theta$  is a dimensionless curvature parameter,  $\alpha$  is the quantum efficiency ( $\text{mg}[\text{CO}_2] \text{ J}^{-1}$ ),  $J_1$  is irradiance on the leaf, and  $P_{\max}$  is the maximum rate of leaf photosynthesis ( $\text{mg}[\text{CO}_2] \text{ m}^{-2}$  (leaf)), given by:

$$P_{\max} = \left[ \frac{T - (T_{\min} Q)}{T_{\text{ref}} - (T_{\min} Q)} \right] J_0 \quad (3:7)$$

where  $Q$  is maximum photosynthesis at the reference temperature ( $T_{\text{ref}}$ ),  $T_{\min}$  is the minimum temperature for photosynthesis,  $T$  is air temperature, and  $J_0$  is total irradiance at the canopy surface.

Potential canopy photosynthesis ( $P_d^g$ ) can also be obtained by solving the following integral:

$$P_d^g = \int_0^{\infty} (h - h_{0s} e^{-kl}) P_1(kJ_{0d} e^{-kl}) + h_{0s} e^{-kl} P_1(kJ_{0s} + kJ_{0d} e^{-kl}) \quad (3:8)$$

### ***Specific Leaf Area***

The model of Woodward (1998) and Woodward *et al.* (1998) uses a constant for specific leaf area (SLA) which is the area per unit weight of leaf. However, available information indicates that SLA in grasses is variable and dependent on the amount of light received (Silsbury, 1971; Vartha, 1972; Jeangros and Nosberger, 1992). SLA is used to estimate LAI which in turn is used in the light capture sub-model for the calculation of potential photosynthesis and respiration losses.

$$LAI = V (SLA) \quad (3:9)$$

where  $V$  is the leaf mass ( $\text{kg ha}^{-1}$ )

It has been observed that LAI increases with decreasing light intensity (Hunt and Burnett, 1973) due to decreasing SLA with increasing light intensity (Silsbury, 1971; Jeangros and Nosberger, 1992). Silsbury (1971) and Jeangros and Nosberger (1992) suggest a general pattern of response in SLA of the form:

$$SLA = SLA_D - SLA_{MIN} (1 - e^{-cW}) \quad (3:10)$$

which is adopted in the model of Bywater *et al.* (1999);  $SLA_{MIN}$  is the minimum sustainable SLA,  $SLA_D$  represents the difference between  $SLA_{MIN}$  and the SLA when the canopy is grown in the dark,  $c$  is an instantaneous rate and  $w$  is average radiation receipt in watts.

This provides a model of changes in SLA of a leaf with the total amount of radiation received. The SLA of a canopy ( $SLA_C$ ) can then be represented by the equation:

$$SLA_C = \sum_{i=1}^A n_i SLA_i \quad (3:11)$$

where  $A_1$  is the age of the oldest leaf,  $n_i$  is the proportion of leaf appearances  $i$  days ago, and  $SLA_i$  is the SLA of those leaves which appeared  $i$  days ago.

### ***Growth Sub-model***

Growth ( $G$ ) as defined by Woodward (1998) is generated from vegetative leaf and stem and reproductive leaf.

$$G = \frac{\pi Y \left( p_d^g L_{CAP} - \Gamma_{MAINT} \right)}{\gamma} \quad (3:12)$$

where  $\pi$  is the proportion of assimilate going to vegetation,  $Y$  is the efficiency of synthesis of dry matter,  $\gamma$  is a constant converting  $[CO_2]$  into DM ( $161 \text{ mg}[CO_2] \text{ kgDM}^{-1}$ ),  $p_d^g$  is potential canopy photosynthesis as defined above,  $L_{CAP}$  is light capture by the various components of the sward and  $\Gamma_{MAINT}$  is maintenance respiration given by:

$$\Gamma_{MAINT} = \frac{k_r^1}{LAI} \times V \times e^{k_r^2(T-T_d)} \quad (3:13)$$

where  $T$  is current temperature,  $T_d$  is developmental temperature, and  $k_r^1$  and  $k_r^2$  are respiration parameters.

Once daily growth is calculated for all components, loss due to senescence is calculated as:

$$\sigma_V = a \times T_d + b \quad (3:14)$$

where  $a$  and  $b$  are estimated parameters

Change in vegetation green cover ( $V$ ) is then given by:

$$\frac{dV}{dt} = nG - \sigma_V \quad (3:15)$$

where  $n$  represents a species in a sward. Changes in dead material ( $D$ ), based on the decay rate ( $d$ ) given by Woodward *et al.* (1998) is calculated as:

$$\frac{dD}{dt} = \sigma_V - dD \quad (3:16)$$

More details on parameters  $h$  and  $J$  which are site dependent are given in section 3.1.3. The parameters  $P_{max}$ ,  $\kappa$ ,  $\alpha$ ,  $\theta$ ,  $\pi$ , and  $Y$  are all plant and/or canopy specific and independent of site. Therefore, given a set of plant and/or canopy parameters estimated from one site, it would be possible to transfer the estimates to a second site and be able to predict the growth rates.

### ***Assimilate Partitioning***

The models of Woodward (1998) and Woodward *et al.* (1998) represent the amount of assimilate partitioned between vegetative and root material as a constant. However, Parsons

and Robson (1981) showed that the fraction of assimilate partitioned to shoot growth ( $\omega$ ) changes with the reproductive development of the sward. Woodward (1998) and Woodward *et al.* (1998) observed that their model is sensitive to this parameter. Bywater *et al.* (1999) defined a cubic function to represent this factor in the LincFarm model. The equation is defined as:

$$\omega = a \times (d - d_0)^3 + b \times (d - d_0)^2 + c \times (d - d_0) + k \quad (3:17)$$

where  $d$  is the current day of the year,  $d_0$  is a reference day, and  $a$ ,  $b$ ,  $c$  and  $k$  are fitted parameters.

### ***Reproduction Sub-model***

The reproductive model simply controls the time at which material switches from a vegetative to a reproductive state and vice versa. There is no change from the methodology presented by Woodward *et al.* (1998). However, the model is implemented independently for each separate pasture species such as ryegrass, clover, etc.; values of 0 for the parameters result in no reproductive growth occurring.

### **3.1.2. Site Dependent Sub-models**

#### ***Radiation Sub-model***

The radiation sub-model used by Bywater *et al.* (1999) is as reported in Woodward (1998) and is based on work by Johnson *et al.* (1996) who presented a scheme that uses mean daily irradiance ( $J_0$ ) and day length ( $h$ ) to estimate the number of hours in a day receiving full sun ( $h_{0,s}$ ) and the mean daily direct beam and diffuse irradiance at the top of the canopy  $J_{0,s}$  and  $J_{0,d}$  J (PAR)m<sup>-2</sup> (ground) S<sup>-1</sup>. PAR denotes photosynthetically active radiation following the observation that the photosynthetic response of plants to direct sunlight is less efficient than the response to diffuse light—that is, light received from clouds and blue skies.

Day length  $h$  is calculated by:

$$h = \frac{24}{\pi} \cos^{-1}(\tan \lambda \tan \delta) \quad (3:18)$$

where  $\lambda$  is the latitude (negative for the southern hemisphere) and  $\delta$  is the solar declination angle (in radians) on the current day of the year calculated as:

$$\delta = -0.4084 \cos\left(2\pi \frac{d+10}{365}\right) \quad (3:19)$$

where  $d$  is the Julian date, or time of the year in days measured from 1 January.

In clear skies, the direct beam light is:

$$J_{0,s} = 1367 \times \frac{2P}{\pi} \times \sin\phi \tau \frac{1}{\sin\phi} \quad (3:20)$$

where  $1367 \text{ W m}^{-2}\text{s}^{-1}$  is the solar constant (solar flux density perpendicular to the beam, outside the atmosphere) and  $P$  is the relevant fraction of radiation in full spectrum sunlight (here assumed to be unity). The parameter  $\tau$  is the clear sky transmissivity at the site, which represents the degree of absorption and scattering of solar radiation as it passes through the atmosphere. Analysis of climate data from various parts of New Zealand (Woodward *et al.*, 1998) suggests that equation 3:21 gives a good representation of the atmospheric transmissivity and fits well for range of values utilised by Bywater *et al.* (1999) between 0.3 and 0.7 (see Table 3-1).

$$\tau = 0.64 + 0.12 \cos\left(2\pi \times \frac{d-176}{365}\right) \quad (3:21)$$

and  $\phi$  is the solar elevation angle at local noon estimated as:

$$\phi = \sin^{-1}(\sin\lambda \sin\delta + \cos\lambda \cos\delta) \quad (3:22)$$

The diffuse portion of the irradiance is approximated by:

$$J_{0,d} = 1367 \times \frac{P}{\pi} \times \sin\phi \left(1 + \tau \frac{1}{\sin\phi}\right) \quad (3:23)$$

The requirements for the site are a record of daily radiation and the site's latitude whose values are given in Table 3-1 as used in the current research context.

**Table 3.1:** Radiation parameters utilised in Bywater *et al.* (1999) model

Parameter	Description	Units	Value
Latitude	location of the site	rad <sup>1</sup>	-0.758
Taumin	minimum light transmittivity	%	0.3
Taumax	maximum light transmittivity	"	0.7
TaumaxDay	the day when Taumax occurs	day	176
Solar_Const	watts hitting earth's atmosphere	J S <sup>-1</sup>	1367
$b$	calculated parameter	-	0.46
$J_0$	daily irradiance hitting top of canopy	MJ m <sup>-2</sup> day <sup>-1</sup>	<i>user input</i>
$T$	mean daily temperature	°C	"
$d$	time of year	day	"

<sup>1</sup>Negative for the southern hemisphere

Assuming  $f_{\text{cloud}}$  represents the proportion of the cloud diffuse radiation, which is a fraction of  $J_{0,d}$ , and  $f_{\text{clear}}$  is the remaining proportion represented by clear sky diffuse radiation then:

$$f_{\text{clear}} = \frac{1 - \tau \frac{1}{\sin\phi}}{1 + \tau \frac{1}{\sin\phi}} \quad (3:24)$$

and a relationship of the form shown in equation 3:25 is suggested in estimating  $f_{\text{cloud}}$  by Johnson *et al.* (1995).

$$f_{\text{cloud}} = b \sqrt{\frac{J_0}{J_{0,d}}} \quad (3:25)$$

A value of 0.46 is suggested for the calculated parameter  $b$  (see Table 3-1).

Utilising equation 3:26, it is possible to estimate  $h_{0,s}$  as:

$$h_{0,s} = h \left[ \frac{J_0 - f_{\text{clear}} J_{0,d}}{(1 - f_{\text{clear}}) J_{0,d}} \right] \quad (3:26)$$

### ***Soil Moisture Sub-model***

Bywater *et al.* (1999) adopted a soil moisture model previously described by Scotter *et al.* (1979) which was also used by Woodward (1998) and Woodward *et al.* (1998). The Scotter *et al.* (1979) model is dependent on measurement of soil parameters and was developed on the basis of values from a site in Palmerston North, New Zealand.

Potential evapo-transpiration ( $PET_w$ ) is calculated for a saturated soil using the model of Priestly and Taylor (1972) and the Scotter *et al.* (1979) model for an unsaturated soil ( $AET_s$ ) utilising parameter values reported in Baker *et al.* (1985). Where soil has been wetted by recent rains or irrigation,  $ET_w$  is used, otherwise the smaller of  $ET_w$  and  $AET_s$  is utilised. The equation for  $AET_s$  (Scotter *et al.*, 1979) is derived from a model describing water loss from a saturated soil over time described by the daily soil water deficit (SWD) which represents water shortage below field capacity of the soil following extraction by drainage, evaporation from the soil and transpiration by plants.

$$SWD = a \left( 1 - e^{-bt} \right) \quad (3:27)$$

where  $a$  represents the maximum water available in the soil and  $b$  is the instantaneous

rate of loss for a fully saturated soil. The  $a$  can be rewritten as:

$$a = AWHC (\text{CurrentWaterContent} + SWD) \quad (3:28)$$

where AWHC is the available water holding capacity

The derivative of equation 3:28 could be rewritten in terms of SWD as:

$$\frac{dy}{dt} = AET_s = -b (SWD) + ab \quad (3:29)$$

The value  $ab$  represents the amount of evapo-transpiration when the soil is saturated (when  $SWD=0$ ).

Thus  $b$  is calculated as:

$$b = \frac{PET_w}{-AWHC} \quad (3:30)$$

Substituting term  $ab$  with  $PET_w$  and the  $b$  with equation 3:30, equation 3:31 can be expressed as:

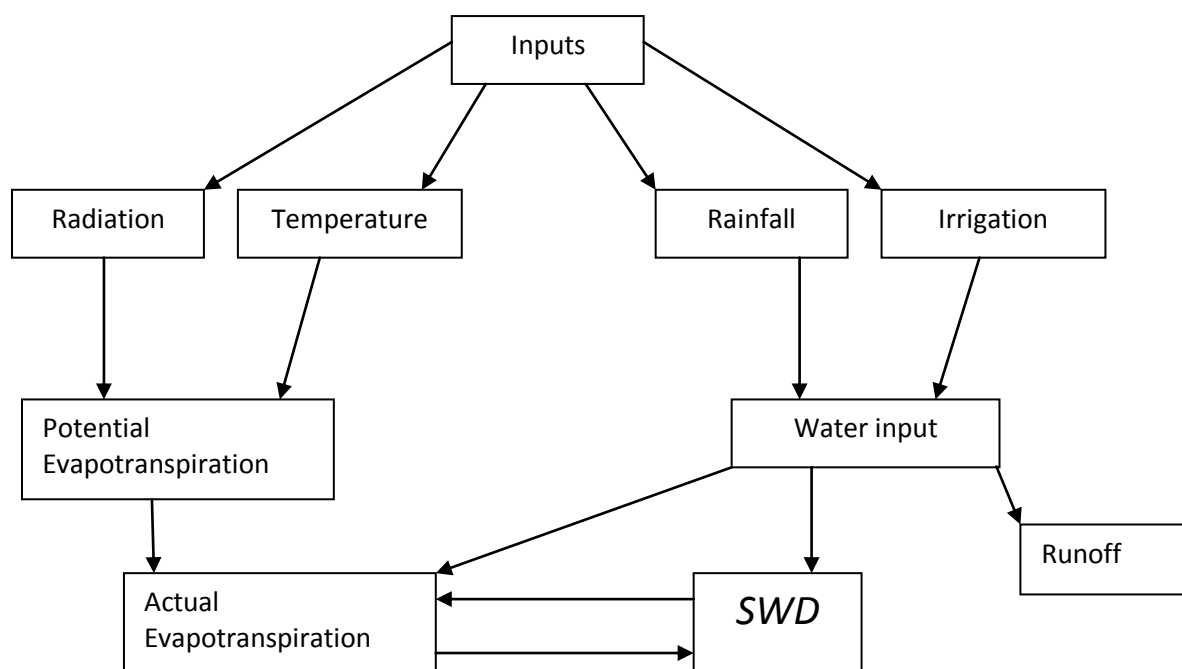
$$AET_s = \frac{PET_w}{AWHC} SWD + PET_w \quad (3:31)$$

With equation 3:31 the value of  $b$  does not require to be re-estimated for every soil type and site.

Bywater *et al.* (1999) revised some aspects of the model described above where soil moisture status was described by SWD as shown in Figure 3-2.

In order to determine changes in SWD, mean daily air temperature ( $T$ ; °C), radiation ( $Rad$ ; MJ day<sup>-1</sup>), and water input (rainfall— $RF$ ; mm day<sup>-1</sup> and/or irrigation) are required.

The  $T$  and  $Rad$  are used in determining potential evapo-transpiration which is the combined effect of soil moisture extraction through evaporation and plant transpiration.



**Figure 3-2:** Diagrammatic representation of the soil moisture status sub-model

Irrespective of whether there is rain or not, a value for RF is required and is set to zero for rainless days. The irrigation capability is an optional management tool and is decided by the user. Where it is utilised, it is assumed to add 50.0 mm of water to the soil. Table 3-2 presents the parameters and their respective values for the soil moisture model utilised by Bywater *et al.* (1999).

**Table 3.2:** Soil moisture parameters utilised in Bywater *et al.* (1999) model

Parameter	Description	Units	value
$\alpha$	Calculated parameter	-	1.26
$\gamma$	Calculated parameter	-	0.661
d	Depth at which water is easily available	mm	300
AWHC	Total available water	mm ha <sup>-1</sup>	132, 100
L	Proportion of water input lost	-	0.4
Rad	radiation receipt	MJ m <sup>-2</sup> day <sup>-1</sup>	<i>user input</i>
T	Temperature	°C	"
RF	Rainfall	mm day <sup>-1</sup>	"

SWD is determined following the determination of potential and actual evapotranspiration, and water input calculation.

Maximum daily evapo-transpiration is estimated using the formula described by Priestly and Taylor (1972) as:

$$PE_{T_w} = \alpha R_n \times \frac{S}{\gamma + S} \quad (3:32)$$

where  $R_n$  is net radiation receipt in MJ day<sup>-1</sup>,  $S$  is a psychometric constant and  $\alpha$  and

$\gamma$  are calculated parameters. Their values in the current context are given in Table 3-2.

Scotter *et al.* (1979) estimated  $R_n$  as:

$$R_n = \frac{Ra_d}{2.46} \quad (3:33)$$

and:

$$S = 6.108 \exp \left( 17.2694 \times \frac{T}{(T + 237.3)^2} \right) \quad (3:34)$$

Actual evapo-transpiration is affected by the available proportion of soil water and its distribution in the rooting zone with the amount of water removed being dependent on the proportion of available water and the potential water loss. Actual evapo-transpiration is thus calculated as:

$$AET = \frac{PET}{AWHC} SWD + PET \quad (3:35)$$

AWHC is defined experimentally as the water held between field capacity to a given soil depth (typically  $-0.01$  MPa) and the permanent wilting point (PWP) which is the point where a plant ceases to grow (typically  $-1.5$  MPa) (Scotter 1977; Rickert 1984); at that point:

$$SWD = AWHC \quad (3:36)$$

The limit at which no water stress is detectable is defined as such a point that SWD results in the same growth as a fully irrigated crop (Woodward, 1998). AWHC can be established through measurements in the laboratory and tabulations exist for most New Zealand soils (Gradwell 1968, 1971, 1974; Griffiths 1985). A value of  $132,100 \text{ mm ha}^{-1}$  was utilised for AWHC in this study as shown in Table 3-2.

It is important to observe that, if the soil has recently been wetted through irrigation and/or rainfall and the water is not evenly distributed, plants are more likely to remove more water from the upper zones (Bywater *et al.*, 1999). Thus a depth ( $d$ ) dependent model is used in estimating  $AET_{sd}$ :

$$AET_{sd} = \frac{PET_w}{AWHC_d} SWD_d + PET_w \quad (3:37)$$

When the soil has reached moisture saturation point, any further water input is lost as runoff. Bywater *et al.* (1999) tested this notion against data from Winchmore and concluded that this did not adequately account for the difference between water input and actual soil

moisture since other factors such as wind and soil porosity account for a percentage of water loss even when the soil is not completely saturated. They introduced a correcting factor for use on estimating effective water input (WI).

$$WI = (RF + Irr) \times (1 - W_1) \quad (3:38)$$

where Irr is irrigation (mm day<sup>-1</sup>) and W<sub>1</sub> is the proportion of water lost by other means other than runoff and evapo-transpiration.

Based on the estimated evapo-transpiration and effective water input, soil moisture deficit is updated as:

$$SWD_t = SWD + WI \quad (3:39)$$

Equation 3:39 follows changes due to water input while equation 3:40 updates soil moisture deficit following loss due to evapo-transpiration:

$$SWD_t = SWD + WI - AET \quad (3:40)$$

Equations 3:41 and 3:42 change soil moisture deficit depending on whether soil water runoff (R<sub>0</sub>) is less or greater than zero respectively.

If R<sub>0</sub> < 0:

$$SWD_t = SWD^{\hat{}} + WI - AET \quad (3:41)$$

or:

$$SWD_t = SWD^{\hat{}} + WI - AET - R_0 \quad (3:42)$$

where SWD<sup>̂</sup> is the previous day's soil moisture

### 3.1.3. Site and Growth Interactions Sub-models

#### *Water Stress Sub-model*

The water stress model used by Bywater *et al.* (1999) is a modification of that used by Woodward *et al.* (1998) who used values obtained by Parfitt *et al.* (1985) to determine the upper and lower soil moisture limits. Table 3-3 shows values used by Bywater *et al.* (1999) for field capacity and water holding capacity.

**Table 3.3:** Values of field capacity and available water holding capacity used in Bywater *et al* (1999) water stress model

Depth (mm)	FC	AWHC
100	29.7	21.0
300	35.0*	53.2
1250	-	100.0

\*Obtained by calculation from the values of soil moisture content in top 10 cm between 1960-1970

Following an examination of the average soil moisture deficit and pasture growth rates for 20.0% irrigated and non-irrigated trials at Winchmore between 1960 and 1970, Bywater *et al.* (1999) estimated the start of water stress as occurring from values of -10.0 and -6.0 at depths of 1250.0 and 300.0 mm respectively. The value of 1250.0 mm is assumed to represent the maximum depth of water availability to pasture. The -10.0 and -6.0 limits formed the basis of determining the functions necessary in estimating water stress ( $G_w$ ):

$$G_w = \text{MAX}(L_1, L_2) \quad 300 \leq G_w \leq 1 \quad (3:43)$$

where:

$$L_1 = 1 - \frac{-\text{SWD} - 10}{\text{AWHC} - 10} \quad (3:44)$$

and:

$$L_2 = 1 - \frac{-\text{SWD}_t - 6}{\text{AWHC}(300) - 6} \quad (3:45)$$

This water stress modifier is extended to act on the growth equation as:

$$G = G_w \times \frac{\pi Y \left( P_d^g \text{cap-maint} \right)}{\gamma} \quad (3:46)$$

### **Light Capture Sub-model**

Light capture in the Woodward (1998) model is included within the growth equations. However, a generalised algorithm that enables the light capture by particular species components within a sward to be calculated was extracted by Bywater *et al.* (1999) and allows each component of a mixed sward to be modelled separately.

A sward consists of  $n$  species each having  $i$  components of mass  $M_{ni}$ . There are  $j$  layers in the sward and  $P_{nij}$  is the proportion of  $M_{ni}$  in layer  $j$ .  $C_{ni}$  is the light capturing ability of component  $ni$ .

The light extinction of component  $n_{ij}$  is thus:

$$k_{n_{ij}} = C_{n_j} M_{n_j} P_{n_{ij}} \quad (3:47)$$

Given:

$$K = \sum_{j=1}^J K_j \quad (3:48)$$

where  $K$  is the total light extinction over all layers in the canopy and  $K_j$  is extinction over one layer given by:

$$K_j = \sum_{n=1}^N K_{nj} \quad (3:49)$$

$K_{nj}$  is extinction by one species within a layer and is given by:

$$K_{nj} = \sum_{i=1}^I K_{n_{ij}} \quad (3:50)$$

where  $K_{n_{ij}}$  is the light extinction by each component of each species within each layer.

Available light is then:

$$AL_j = e^{-k'_n k_j} \quad (3:51)$$

where  $k'$  is defined as the attenuation factor for photosynthesis for each species rather than for light (Woodward, 1998) and light which is extinguished:

$$EL_{nj} = e^{-k'_n k_{nj}} \quad (3:52)$$

The light capturing ability of component  $n_i$  is then:

$$cap_{n_i} = \sum_{j=1}^J AL_{nj} \left(1 - EL_{nj}\right) \frac{k_{n_{ij}}}{k_j} \quad (3:53)$$

### 3.2. Leaf Death and Litter Disappearance

Leaf life span (LS) is based on temperature such that:

$$LS = \frac{1}{\sigma(T + 2.2)} \quad (3:54)$$

where  $\sigma_v$  is loss due to senescence (see equation 3:14)

Leaf death is an important process as it affects the pasture quality in a grazing system

since it drives the production of dead material in the pasture. The rate of vegetative leaf death ( $D_{\text{vleaf}}$ ) is linear with respect to vegetative green mass ( $V$ ) (Woodward, 1998) such that:

$$D_{\text{vleaf}} = \alpha_v V \text{ (kg ha}^{-1} \text{ day}^{-1}\text{)} \quad (3:55)$$

The dead material moves to the dead material pool where the two main processes affecting its disappearance in pasture are microbial decomposition and removal by earthworms. Microbial decomposition is dependent on moisture and temperature (McCall, 1984; Hunt *et al.*, 1991) and has been shown to be a first order process (Hunt 1977; Yates 1982; Hirata, 1992; Bloemhof and Berendse, 1995), so that the rate of litter disappearance ( $rLD$ ) in Woodward (1998) and Woodward *et al.* (1998) is modelled as:

$$rLD = \delta_d \times d_T \times d_w D \quad (3:56)$$

where the effects of temperature and moisture are modelled through the factors  $d_T$  (decomposition temperature factor) and  $d_w$ . (water stress decomposition factor) and  $D$  is the dead matter.

Litter is also removed by earthworms and is dependent on the earthworm populations at a particular time of year (Martin, 1978; Marinissen, 1992; Baker *et al.*, 1992, 1993; Fraser and Piercy, 1996), how close they are to the surface (Marinissen, 1992; Baker *et al.*, 1992, 1993), the quantity of available litter (Daniel, 1991; Edwards and Bohlen, 1996) and their activity (Daniel, 1991). The population and depth are primarily driven by soil moisture and temperature (Fraser and Piercy, 1996; Edwards and Bohlen, 1996). Woodward (1998) model assumed earthworm removal as a first order process so that the rate of litter removal ( $rLR$ ) is:

$$rLR = \delta_e \times e_T \times e_w BD \quad (3:57)$$

where  $\delta_e$  is a constant and the moisture and temperature dependence is modelled through the factors  $e_w$  and  $e_T$  and  $B$  is earthworm biomass in the top 10.0 cm of soil and is calculated as:

$$B = 0.2 \times D \quad (3:58)$$

### 3.3. Animal Model

The animal sub-model is described in detail in Finlayson *et al.* (1995) with the exception of the animal reproduction component which is presented in Cacho *et al.* (1995). The original version of the model was intended to simulate grazing sheep. With the introduction of beef into high performance dryland sheep systems to provide flexibility to manage climatic variability and to aid in cleaning excess pasture in the sheep systems, a beef

growth and composition component needs to be added to the Linfarm model and this is detailed in Chapter 5.

### 3.3.1. Animal Reproduction

The animal reproductive performance sub-model is designed to predict ewe conception rates. It incorporates the effects of LW change which can occur due to changes in feed quality and quantity as is the case with ewe flushing prior to mating. The change in LW helps in estimating the number of ewes in a mob producing multiple ovulation and is described in detail in Cacho *et al.* (1995). The number of ewes considered to conceive ( $C_{ne}$ ) in a flock following mating is obtained from:

$$C_{ne} = Pr_c \times \chi \times E_{np} \quad (3:59)$$

where  $Pr_c$  denotes the probability of conception on a given day,  $\chi$  represents the proportion of cycling ewes on a given day and  $E_{np}$  is the number of non-pregnant ewes in a flock. The  $Pr_c$  is considered to conform to a trapezoidal shape as presented in Finlayson *et al.* (1995):

$$Pr_c = \begin{cases} \xi \frac{t - \tau_1}{\tau_2 - \tau_1} & \text{If } \tau_1 < t \leq \tau_2 \\ \xi & \text{If } \tau_2 < t \leq \tau_3 \\ \xi \left[ 1 - \frac{t - \tau_3}{\tau_4 - \tau_3} \right] & \text{If } \tau_1 < t \leq \tau_2 \end{cases} \quad (3:60)$$

where  $\xi$  is the maximum proportion of cycling ewes conceiving on a specific day,  $t$  is the day of the year starting January 1,  $\tau_1$  and  $\tau_4$  are the start and end of the breeding cycle respectively, and  $\tau_2$  and  $\tau_3$  bound the period when  $Pr_c$  is at maximum. The animal model parameters and constants are presented in detail in Finlayson *et al.* (1995).

The proportion of ewes cycling on a given day follows the work presented by McCall (1984) such that:

$$\chi = \begin{cases} 0 & \text{If } E_{ALW} < 18.5 \\ -\beta_0 + \beta_1 E_{ALW} - \beta_2 E_{ALW} & \text{If } 18.5 < E_{ALW} \leq 50.0 \\ 1 & \text{If } E_{ALW} > 50.0 \end{cases} \quad (3:61)$$

where  $E_{ALW}$  is the average LW of the flock and constants  $\beta_0$ ,  $\beta_1$  and  $\beta_2$  equal 1.5216, 0.102 and 0.00104 respectively.

A review carried out by Coop (1966) concluded that there is an improvement in

lambing percentage as a result of an increased feeding plane for ewes prior to mating (flushing) which is either due to a static and/or dynamic effect represented by LW at mating or LWG prior to mating respectively. The work by Rattray *et al.* (1980 and 1981) showed that these two effects influence multiple ovulation (MO). They noted an increased response to flushing in light ewes compared to their heavier contemporaries. The probability of MO was thus considered in the light of the two effects as:

$$MO = MO_S + MO_D \quad (3:62)$$

where the subscripts S and D represent the static and dynamic effects respectively. MO refers to the production of two eggs in the current context and the possibility of it resulting in conception of triplets is ignored (Cacho *et al.*, 1995). The static effect is defined in terms of EBW (kg head<sup>-1</sup>):

$$MO_S = \psi - \eta \left[ \left[ \frac{EBW}{EBW_{MAX}} \right]^2 - 2 \times \frac{EBW}{EBW_{MAX}} + 1 \right] \quad (3:63)$$

where  $\psi$  is the probability of MO of a ewe whose LW remained constant at  $EBW_{MAX}$  in the period two weeks before mating and  $\eta$  is a constant. Based on the quadratic nature of equation 3:63, both under- and over-weight ewes have a reduced probability of MO compared to mature animals of normal weight (Cacho *et al.*, 1995). The dynamic effect was computed in terms of weight change prior to mating as:

$$MO_D = (1 - \psi) \left[ 1 - \exp(-\kappa EBW_{GAIN}) \right] \quad (3:64)$$

where  $EBW_{GAIN}$  is the proportion of EBW gained during the flushing time and  $\kappa$  is a constant. Total MOs were constrained to 1 by including  $\psi$  in computation of both  $MO_S$  and  $MO_D$  effects. Respective values of 0.85, 5.3125 and 2.366 for  $\psi$ ,  $\eta$  and  $\kappa$  were used in estimating both  $MO_S$  and  $MO_D$  in Cacho *et al.* (1995). It is assumed that no multiple ovulations occur when EBW is less than 0.6 of  $EBW_{MAX}$ , and that 80.0% of the multiple ovulations produce two embryos. It is also assumed that embryonic survival is constant making it independent of nutritional effects.

### 3.3.2. Animal Feed Intake

The daily metabolisable energy intake (MJ ME days<sup>-1</sup>) of sheep can be obtained from pasture, hay and/or milk for suckling lambs and is defined as:

$$MEI = MEI_{Pas} + MEI_{Hay} + MEI_{Milk} \quad (3:65)$$

where  $MEI_{Pas}$ ,  $MEI_{Hay}$  and  $MEI_{Milk}$  refer to energy intake from pasture, hay and milk respectively.

There are alternative approaches to predicting feed intake by grazing animals as described in Elsen *et al.* (1988) many of which consider the intake as a product of the potential feed intake by a specified animal and a proportion of that potential (relative intake) that the animal can obtain from the available feed supply (Freer *et al.* 1997). In the LincFarm grazing sheep model, feed intake is determined by the interplay of metabolic energy requirements, physical capacity of the rumen and pasture availability. The energy obtained from pasture intake is given by:

$$MEI_{Pas} = I_{Pas} + E_{Pas} + \delta_{Pas} \quad (3:66)$$

where  $I_{Pas}$  is pasture intake in kg DM day<sup>-1</sup>,  $E_{Pas}$  is the energy content of pasture in MJ ME kg<sup>-1</sup> digestible DM<sup>-1</sup>,  $\delta_{Pas}$  is pasture digestibility.

The pasture intake is estimated by:

$$I_{Pas} = I_{Max} + P_{Ipas} \quad (3:67)$$

where  $I_{Max}$  denotes the potential animal intake in kg DM and  $P_{Ipas}$  is the proportion of potential intake that is achieved and is a function of pasture availability. Assuming that feed availability is non-limiting, the potential intake is calculated as the minimum of the physical ( $I_{PHY}$ ) and metabolic ( $I_{MET}$ ) limits as:

$$I_{Max} = \text{MIN} (I_{PHY}, I_{MET}) \quad (3:68)$$

The physical control of intake is a function of rumen capacity, rate of feed breakdown in the rumen, and the rate of gastric emptying (Bines, 1971). Kahn and Spedding (1984) estimated  $I_{PHY}$  as:

$$I_{PHY} = \frac{\gamma_1 \times R_{CAP}}{1 - \delta_{Pas}} \quad (3:69)$$

where  $R_{CAP}$  is rumen capacity in kg DM and  $\gamma_1$  is the rate at which undigested material is removed and is given in kg DM kg<sup>-1</sup>  $R_{CAP}$ <sup>-1</sup>. The  $R_{CAP}$  is defined as the quantity of substrate that is taken in the rumen before distension causes ingestion to cease and is assumed to be a function of animal LW (Grovmum, 1979) such that:

$$R_{CAP} = \gamma_2 \times LW_{F0} \times 1 + \frac{ME_{REP}}{ME_{I_{NR}}} \quad (3:70)$$

where the  $\gamma_2$  is the ratio of  $R_{CAP}$  in kg DM  $kg^{-1}LW^{-1}$ ,  $LW_{F0}$  is the fleece-free LW,  $ME_{REP}$  represents the increase in  $I_{MET}$  that is associated with reproductive process and  $ME_{I_{NR}}$  is the metabolic requirements for non-reproductive processes estimated by Oltjen *et al.* (1986a) as:

$$ME_{I_{NR}} = \gamma_3 - \left[ \frac{\gamma_4^{EBW}}{EBW_{MAX}} \right] \times EBW^{0.73} \quad (3:71)$$

where  $EBW_{MAX}$  is the EBW of normally fat animal at maturity and  $\gamma_3$  and  $\gamma_4$  are estimated parameters whose values and description are presented in Finlayson *et al.* (1995). Estimates of  $EBW_{MAX}$  for ram, wether and ewe were given as 85.8, 80.0 and 66.7 respectively for meat breed, 76.1, 72.0 and 60.2 for wool breeds and 81.5, 76.0 and 63.7 for half breed sheep in New Zealand (St-Pierre and Bywater, 1987).

During the reproductive cycle, a temporary imbalance occurs between energy expenditure and intake which results in loss of fat through pregnancy and early lactation, before condition is regained in late lactation. During pregnancy the development of the conceptus involves an exponential increase in the additional energy demand of the pregnant animal (SCA, 1990). However, there is no evidence of increase in the voluntary feed intake (Weston 1982). Forbes (1968) suggested that the space taken up by the conceptus in the body cavity is compensated for by a decrease in mean retention time of digesta in the gut. Converse to pregnancy, work reviewed by ARC (1980) showed that lactation has the potential to increase intakes by as much as 60% in both cows and sheep. The effect of the reproductive requirements on intake is calculated as:

$$ME_{I_{REP}} = \sum_{i=1}^t \left( REP_{t-i} + 1 - REP_{t-i} \right) \times \left( 1 - \gamma_5^i \right) \quad (3:72)$$

where  $REP$  is the ME required for reproduction given in MJ ME  $day^{-1}$ ,  $t$  is days since conception and  $\gamma_5$  is a delay factor. The value of  $REP$  depends on the ewe's reproductive status:

$$REP_t = \begin{cases} ME_{PREG} & \text{If } t \leq 147 \\ ME_{LAC} & \text{If } 147 < t < 365 \end{cases} \quad (3:73)$$

where  $ME_{PREG}$  and  $ME_{LAC}$  represent the energy costs of pregnancy and lactation

respectively.

Bines *et al.* (1969) observed that, in situations where digestibility is non-limiting, animals consume feed at such levels that their body condition is maintained over long periods of time. The long-term regulation of feed intake involves physiological mechanisms by which animals balance energy intake with expenditure (Bines, 1971) such that:

$$I_{MET} = \frac{MEI_{NR}}{E_{pas} \times \delta_{pas}} \quad (3:74)$$

The proportion of maximum intake ( $P_{I_{pas}}$ ; see equation 3:67) is estimated as a function of pasture availability as described in McCall (1984) so that:

$$P_{I_{pas}} = \Omega_{ha} \exp[-\gamma_6 \exp(-\gamma_7 \notin_A)] \quad (3:75)$$

where  $\notin_A$  and  $\Omega_{ha}$  represents per head and per hectare pasture availability respectively, and:

$$\notin_A = \frac{GDM}{I_{MAX}} \times \frac{S_{pad}}{N} \quad (3:76)$$

and:

$$\Omega_{ha} = 1 - \gamma_8 \exp[-\gamma_9 (S_{pad})] \quad (3:77)$$

where GDM is the amount of green dry matter in the sward given in  $kg\ ha^{-1}$ ,  $S_{pad}$  is the size of the paddock in hectares and  $N$  is the number of animals grazing the paddock. At low levels of pasture availability,  $P_{I_{pas}}$  is calculated by linear interpolation between 0 and equation 3:75 (McCall, 1984).

Grazing animals show different preferences to sward elements resulting in higher digestibility of the ingested material compared to the overall digestibility of the grazed pasture (Christian, *et al.*, 1978; Geenty and Sykes, 1982). An animal is assumed to satisfy its potential feed intake from each sward elements in succession starting with the elements of highest quality and with the extent to which the animal eats herbage of progressively lower quality depending on the weight of herbage in each element class (SCA, 1990). The ratio of leaf, stem and dead material in the diet selected by an animal is estimated by Michaelis-Menten functions so that:

$$V_{Elm} = \frac{\mu_{Elm} C_{Elm}}{k_{Elm} + C_{Elm}} \quad (3:78)$$

where  $E_{lm}$  represents leaf, stem or dead material proportion,  $V_{elm}$  is the actual rate and  $\mu_{elm}$  is the maximum rate at which component  $elm$  is consumed and is given in  $kg\ DM\ kg^{-0.75}\ LW\ day^{-1}$ . More details of individual component consumption rate (leaf, stem and dead material) are presented in Cacho *et al.* (1995).

The energy derived from hay ingestion is estimated as:

$$MEI_{Hay} = I_{Hay} \times E_{Hay} \times \delta_{Hay} \quad (3:79)$$

and hay consumption ( $I_{Hay}$ ) is calculated as a function of the number of animals in the flock ( $N$ ; head), the amount of hay available to the flock ( $HAY$ ;  $kg\ DM$ ) and the proportion of wastage that occurs in the paddock during feeding ( $W_{Hay}$ ):

$$I_{Hay} = \frac{HAY}{N} \times (1 - W_{Hay}) \quad (3:80)$$

Energy acquired by suckling lambs from milk is estimated by:

$$MEI_{Milk} = I_{Milk} \times E_{Milk} \quad (3:81)$$

Where  $I_{Milk}$  is milk intake per day by a lamb ( $litres\ day^{-1}$ ) and  $E_{Milk}$  is the estimated energy content of milk which is given in  $MJ\ ME\ litre^{-1}$ . Rumen capacity is not considered as a limitation to lamb milk intake since milk consumed by lambs bypasses the rumen. A lamb is assumed to consume milk until its metabolic requirements are met or ewe milk supply is exhausted. Joyce and Rattray (1970) and Penning and Gibb (1979) suggested that, in a scenario where the lamb's metabolic requirements are higher than the ewe milk supply, lambs should be fed on pasture to plug the energy difference. Milk intake is defined as:

$$I_{Milk} = \text{MIN} \left[ \frac{MEI_{NR, Milk}}{E_{Milk}}, Milk \right] \quad (3:82)$$

where  $Milk$  represents the amount of milk available in ewe's udder measured in litres.

### 3.3.3. Maintenance Energy Requirements

There are various factors that determine the energy requirement for maintenance including an animal's metabolic body weight, age, environmental temperature and the energy costs of grazing exercise (Vera *et al.*, 1977; Wallach *et al.*, 1984), so that:

$$MEI_{MAINT} = \beta_4 \times EBW^{0.75} \quad (3:83)$$

Constant  $\beta_4$  could be modelled as a function of air temperature, animal body

temperature, and grazing conditions such as the topography of the grazing area. However, it is presumed that seasonal variations in weather and sward characteristics in the current study area (that is lowland Canterbury, New Zealand), are not so extreme as to require representation of the noted sources of variation and  $\beta_4$  is therefore taken to be constant.

### 3.3.4. Energy Requirements for Pregnancy and Lactation

Energy requirement for pregnancy increases with the progression of gestation and an increase in the number of foetuses carried by an animal (Rattray *et al.*, 1974). The following equation obtained from Bowman *et al.* (1989) is used in estimating the energy requirement for pregnancy in grazing sheep:

$$ME_{\text{PREG}} = \chi_1 \frac{BW}{K_{\text{PREG}}} \times \chi_{\text{PREG}} \exp[\chi_2 - \chi_3 \theta_{\text{PREG}}] \quad (3:84)$$

where BW is total lamb(s) birth weight (kg) estimated from the birth weight of individual lambs ( $LW_0$ ). Table 3-4 presents birth weight for different sire breeds obtained from Finlayson *et al.* (1995).

**Table 3.4:** Lamb birth weight (kg)

Sire breed	Sex	Single	Twin
Wool	Ram	4.8	4.0
	Ewe	4.6	3.9
Meat	Ram	5.3	4.4
	Ewe	5.0	4.2

The  $K_{\text{PREG}}$  is an efficiency factor reflecting ME use for conceptus gain and maintenance,  $\chi_i$  are constants, and  $\theta_{\text{PREG}}$  is:

$$\theta_{\text{PREG}} = \exp \left[ \chi \begin{matrix} \tau \\ 4 \end{matrix} \right] \quad (3:85)$$

where  $\tau$  is day of gestation with energy requirements for pregnancy and lamb birth weights being assumed to be non-responsive to the nutritional status of the ewe. The amount of protein and fat in lambs at birth is estimated utilising equations obtained from ARC (1980):

$$\text{PROT}_0 = \chi_5 \text{EBW}_0^{\chi_6} \quad (3:86)$$

$$\text{FAT}_0 = \chi_7 \text{EBW}_0^{\chi_8} \quad (3:87)$$

where  $\text{EBW}_0$  is lamb's empty body weight at birth, obtained from solving equation 3:112 as a function of  $LW_0$ . Following the work of St-Pierre and Bywater (1987), the amount of DNA at birth can be estimated by solving equation 3:88 as:

$$DNA_0 = \chi_9 LW_0^{\chi_{10}} \quad (3:88)$$

Barnicoat *et al.* (1957) and Jagusch *et al.* (1972) observed that the lactation curve of a ewe increases rapidly from parturition for approximately 3 weeks followed by decline in milk production until lambs are weaned as late as 4 months of age. In the LincFarm model, potential milk yield is predicted using a gamma function and is taken to be dependent on the number of suckling lambs and time since parturition. The actual amount of energy partitioned to lactation is estimated as:

$$ME_L = \Omega_{Milk} NUT_M^T \quad (3:89)$$

where  $NUT_M$  is defined in equation 3:95, and  $\theta_{Milk}$  is potential milk production (MJ ME day<sup>-1</sup>) defined as:

$$\theta_{Milk} = \Omega_{milk} TP^{\chi_{11}} \exp[-\chi_{12} TP] \quad (3:90)$$

where TP is time since parturition expressed in weeks,  $\chi_{11}$  and  $\chi_{12}$  are shape parameters while  $\Omega_{milk}$  is used in determining the amount of milk production based on the number of lambs born as described in McCall (1984):

$$\Omega_{milk} = \begin{cases} -\chi_{13} \times LW_0 & \text{for singles} \\ -\chi_{14} \times (LW_0 + 1) & \text{for twins} \end{cases} \quad (3:91)$$

Milk production can be transformed to litres by:

$$\Delta_{milk} = ME_L \times \frac{K_{milk}}{E_{milk}} \quad (5:92)$$

where  $K_{milk}$  represents the efficiency of milk production and  $E_{milk}$  is the milk energy content per litre.

### 3.3.5. Energy Balance and Nutrition

The model predicts both energy intake and requirement and utilises any energy above an animal's physiological requirements to form fat. Where requirements exceed intake, the difference is obtained from fat catabolism:

$$E_{BAL} = ME_I - (ME_{MAINT} + ME_{PREG} + ME_{LAC} + ME_{PROT} + ME_W) \quad (3:93)$$

where energy requirements for maintenance, pregnancy, protein accretion, wool growth and lactation are represented by  $ME_{MAINT}$ ,  $ME_{PREG}$ ,  $ME_{LAC}$ ,  $ME_{PROT}$  and  $ME_W$

respectively.

The changes in an animal's fat reserves are determined as:

$$\Delta_{FAT} = \begin{cases} \frac{E_{BAL} K_{FAT}}{E_{FAT}} & \text{If } E_{BAL} > 0.0 \\ \frac{E_{BAL}}{E_{FAT}} & \text{If } E_{BAL} \leq 0.0 \end{cases} \quad (3:94)$$

where  $K_{FAT}$  is efficiency of fat synthesis and  $E_{FAT}$  is the ME contained in fat (MJ ME  $\text{kg}^{-1} \text{fat}^{-1}$ ).

Rates of physiological processes are influenced by nutrition (St-Pierre and Bywater, 1987). This aspect was considered as significant in developing LincFarm and was achieved by specifying equations to represent the potential rates of mass and energy transactions with the equations being reduced depending on the nutritional status achieved by the animal.

Following work reported by St-Pierre and Bywater (1987) this result in:

$$NUT_{PWM} = 1 - \frac{\zeta_{PWM}}{\rho_{PWM} + 1} + \frac{\zeta_{PWM} P_N}{\rho_{PWM} + P_N} \quad (3:95)$$

$$NUT_{DNA} = 1 + [P_N - 1] \zeta_{DNA} \quad (3:96)$$

PWM represents protein, wool or milk and  $NUT_{PWM}$  and  $NUT_{DNA}$  represent nutritional factors affecting protein, wool, milk, and DNA synthesis while  $P_N$  is a ratio of available energy to the energy required to meet various physiological processes estimated as:

$$P_N = 1 - \frac{MEI + \beta_1 E_{FAT}^{FAT}}{MEI_{NR} + MEI_{REP} + \beta_1 E_{FAT}^{FAT}_{MAX}} \quad (3:97)$$

where  $\beta_1$  represents the net proportion of fat that can be catabolised per day,  $FAT$  is the actual fat content of the animal in kg and  $FAT_{MAX}$  represents maximum body fat which is defined as:

$$FAT_{MAX} = \beta_2 EBW^{\beta_3} \quad (3:98)$$

When  $NUT$  equals unity, protein accretion, milk production, wool growth and DNA synthesis proceed at potential rates. The objective of considering the fat pool in defining animal nutritional status is intended to incorporate the influence of body condition on observed variations in the rates of metabolic processes (Geenty, 1983).

### 3.3.6. Sheep Growth and Composition

The model developed by Oltjen *et al.* (1986b; Davis Growth Model: DGM) in modelling cattle growth was used as a basis for a model to predict sheep growth and composition by St-Pierre and Bywater (1987). The model is based on fundamental biological concepts of hyperplasia and hypertrophy applied at the whole animal level, and simulates both body weight gain and composition. It is based on the hypotheses of Baldwin and Black (1979) which are: (i) the primary genetic determinant of organ size is the final DNA content of the organ in mature normally grown individuals of that species, and that nutritional status determines the rate of DNA accumulation and whether the maximum DNA content is achieved, (ii) each unit of DNA specifies the ultimate formation of a specific amount of cell material and that nutritional and physiological status determines whether this target is achieved, (iii) the specific activities of enzymes responsible for tissues growth vary exponentially with organ size and that the kinetic properties of these enzymes are relatively constant across species.

The DGM model simulates both body weight gain and composition by varying the DNA, fat and protein accretion on a daily basis. St-Pierre and Bywater (1987) in developing a sheep growth and composition model under New Zealand grazing conditions, and Doyle *et al.* (1989) while developing a simulation model of beef production under rotation grazing followed similar approaches to the DGM. A later version of the model is further developed for predicting beef growth and composition in high performance sheep grazing systems in this study and its performance evaluation against field data shows that it is suitable in simulating New Zealand grazing beef cattle performance as reported in Chapter 5.

### 3.3.7. Protein and DNA Synthesis

The net amount of ME resulting from protein turnover ( $\text{MJ ME day}^{-1}$ ) is:

$$\text{ME}_{\text{PROT}} = \begin{cases} \Delta_{\text{PROT}} \frac{E_{\text{PROT}}}{K_{\text{PROT}}} & \text{If } \Delta_{\text{PROT}} > 0.0 \\ \Delta_{\text{PROT}} E_{\text{PROT}} & \text{If } \Delta_{\text{PROT}} \leq 0.0 \end{cases} \quad (3:99)$$

where  $K_{\text{PROT}}$  is efficiency of protein synthesis and  $E_{\text{PROT}}$  is the energy content of protein ( $\text{MJ ME kg}^{-1}$ ). The rate of protein accretion ( $\Delta_{\text{PROT}}$  in  $\text{kg day}^{-1}$ ) is calculated as the difference between protein synthesis ( $\text{PROT}_{\text{SYN}}$ ) and degradation ( $\text{PROT}_{\text{DEG}}$ ):

$$\Delta_{\text{PROT}} = \text{PROT}_{\text{SYN}} - \text{PROT}_{\text{DEG}} \quad (3:100)$$

Protein synthesis is defined as:

$$PROT_{SYN} = \theta_{PROT} \times \frac{K_{PROT}}{E_{PROT}} \times NUT_{PROT} \quad (3:101)$$

$\theta_{PROT}$  is the energy potentially required for protein synthesis and is a function of DNA such that:

$$\theta_{PROT} = \alpha_1 DNA^{0.73} \times \alpha_{SEX} \quad (3:102)$$

where  $\alpha_1$  represents potential energy usage per unit of DNA and  $\alpha_{SEX}$  incorporates the influence of sex on protein synthesis. Degradation of protein is related to existing levels of body protein:

$$PROT_{DEG} = \alpha_2 PROT^{0.73} \quad (3:103)$$

The change in quantity of DNA (g day<sup>-1</sup>) is a function of current DNA and nutrition:

$$\Delta_{DNA} = \alpha_3 \left[ \frac{EBW_{MAX}}{80} \right]^{-0.27} \times [DNA_{MAX} - DNA] \times NUT_{MAX} \quad (3:104)$$

where  $DNA_{MAX}$  is the amount of DNA at maturity (St-Pierre and Bywater, 1987) and is given by:

$$DNA_{MAX} = \alpha_4 LW_{MAX}^{\alpha_5} \quad (3:105)$$

where  $LW_{MAX}$  is maximum LW and is calculated from  $EBW_{MAX}$  and equation (3:111).

### 3.3.8. Wool Growth

The wool growth of sheep is influenced by an annual rhythm as a result of response to photoperiod. Breed, nutrition, physiological status and animal size influence rates of wool growth (Coop, 1953; Bigham, 1969; Bigham *et al.*, 1978; Corbett, 1979; Sumner, 1979; White *et al.*, 1979; Sumner and Rattray, 1980). Wool growth requires some amount of energy and it is estimated according to animal nutritional status as:

$$ME_{WOOL} = \theta_{WOOL} NUT_{WOOL} \quad (3:106)$$

where  $\theta_{WOOL}$  is the potential energy usage for wool growth, estimated as:

$$\theta_{wool} = EW_0 + \alpha_6 EW_0 \text{SIN} \left[ (t+102) \times \frac{2\pi}{365} \right] \quad (3:107)$$

where  $\alpha_6$  represents an amplitude of seasonal variation in wool growth rate

(Nagorcka, 1979; White *et al.*, 1983) and  $EW_0$  represents the average energy requirements for wool growth ( $MJ ME day^{-1}$ ). Assuming that, for a given breed, the number and productivity of wool follicles per skin area is constant; wool growth can be described in respect to the skin surface or as a constant proportion of metabolic body weight:

$$EW_0 = +\alpha_7 EBW^{0.73} \quad (3:108)$$

where  $\alpha_7$  is a breed-specific parameter. Actual wool growth ( $kg day^{-1}$ ) can be estimated as:

$$\Delta_{wool} = ME_{wool} \frac{K_{wool}}{E_{wool}} \quad (3:109)$$

where  $K_{wool}$  represents efficiency of wool synthesis and  $E_{wool}$  is the energy content of wool.

### 3.3.9. Predicting Body Weight

Empty body weight is predicted from the amount of fat and protein as:

$$EBW = \frac{PROT}{\alpha_8} + FAT \quad (3:110)$$

where  $\alpha_8$  represents the ratio of protein to fat-free empty body weight. The LW is estimated from empty body weight by (ARC, 1980):

$$LW = \begin{cases} 1.06 \times EBW & \text{for pre-ruminants} \\ 1.09 \times (EBW + 2.9) & \text{for ruminants} \end{cases} \quad (3:111)$$

### 3.3.10. Animal Deaths

A critical weight limit ( $EBW_C$ ) is set for each animal class defined in the model to aid in accounting for the effect of nutritional deficiency on animal death rates. The  $EBW_C$  is 1.0, 3.5, 15.0 and 35.0 kg for suckling, and weaned lambs, hogget, and adult sheep respectively. Whenever the average weight of animals in a particular class fall below its set  $EBW_C$ , a proportion of animals in the group estimated using equation 3:112 is assumed to die.

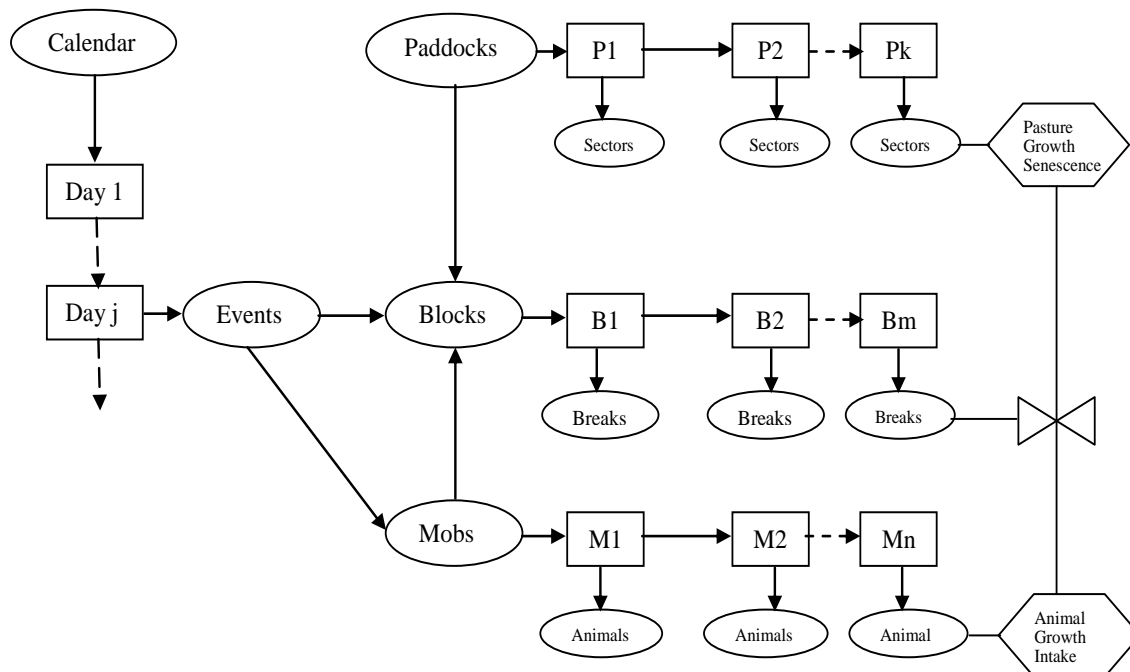
$$A_{death} = 1 - \frac{EBW}{EBW_C} \quad (3:112)$$

where  $A_{death}$  denotes the proportion of animals presumed to die. It is further assumed that the death of a lactating ewe results in death of its lambs if they are less than 30 days old.

Older lambs survive depending on the availability of sufficient herbage of good quality to maintain the lambs in adequate condition. This nutritional deficiency animal death related procedure has been shown to work satisfactory (Cacho *et al.* 1995)

### 3.4. Farm Management Sub-model

Figure 3-3 obtained from Cacho *et al.* (1995) shows the diagrammatic representation of the farm management sub-model.



**Figure 3-3:** Diagrammatic representation of the farm management sub-model. Ellipses represent list of records, boxes show single records, hexagon represent sub-models, and lines depict relationships

#### 3.4.1. The Event Calendar

Managing grazing systems is complicated by the dynamic nature of plants and animals and the need to maximise enterprise profitability (Finlayson *et al.*, 1995). The system management complexity require a corresponding intricate web of management decisions, many of which have to be taken on day to day basis as different situations develop. Christian *et al.* (1978) developed a simulation model which did not only account for the system's biological components but also allowed for the incorporation of detailed decision rules on crop and animal management. This constitutes the idea of an event calendar and is used in LincFarm model. As the model runs, it encounters date-specific events defined by the user which initiate procedures concerned with particular activities. The model management component thus performs a range of necessary functions in response to the occurrence of the event. This forms the link between the management component with the biophysical model which is essentially achieved by restructuring mob and block records according to events in

the management calendar. Table 3-5 shows the data structure which applies to the LincFarm model.

**Table 3.5:** Data structure used in the model

Item	Records
Event	Date Event ID Mob/Block ID Variant Make Block (Paddock list) Destroy Block Grazing Rules (System, Block ID, Rotation length, Break length) Shear Crutch Cull (Year group, Proportion) Replace (Source mob, Replacement record) Castrate Purchase (Animal record) Sell Animals (Minimum EBW, Sex) Flush (Length, Tup record) Tup (Length, Sire breed, Ram mob, Ewe/Ram) Wean (Target mob) Health (Vaccinate, Drench, Dip) Make Hay (Block ID) Feed Hay (Hay record)
Paddock	ID Area Sector List Sampling Record (weighted averages from pasture sectors)
Pasture Sector	Area Dry Matter (Leaf, Stem, Dead) Sampling Record (TDM, GDM, Growth, Senescence, Decay, Intake)
Grazing Block	Area Break List Paddock List
Grazing Break	Area Sector List
Mob	ID Animal List Grazing Record: Rotation Length System (Loner, Leader, Follower) Exit Criterion (Time, Minimum Cover) Block Pointer Hay Record: Number of Days to feed Hay Pool Proportion of Requirements (True/False) Offer (Proportion of Requirements/Pool) Sampling Record (TDM intake, GDM intake, Post-grazing mass)
Animal	Number in Group Body Weight, Protein, Fat, DNA Bounds of Truncated Distribution Wool Energy Intake Breed & Age

**Table 3-5:— Cont'd**


---

Animal	Sex (Wether, Ram, Ewe)
	Ewe Record:
	Reproductive Status (Dry, Pregnant, Lactating)
	Pregnant:
	Sire Breed
	Number of Fetuses
	Lactating:
	Milk Production
	Lamb List
	Sampling Record (N, Age, EBW, Protein, Fat, DNA, Wool, MEI, LW)

---

### 3.4.2. The Event Records

There are a total of 26 management events in the current version of the LincFarm model. An event is designed to be applied to a mob or a block and not to individual animals or paddocks. Therefore, where an event is to be applied to an individual animal group, the target group has to be placed into its own mob and the management event applied to that mob. Similar rules apply in cases where a management event is to be applied to an individual paddock—the individual paddock has to be placed into a block and the management event applied to the block. All event records contain 4 common variables: the date (year and day of the year) in which the event occurs, an identifier number (ID) which indicates type of management event to be implemented on that specific date, and a target index number indicating the mob (a group of animals being managed together) or block (a list of paddock(s) in the farm; considered as the management unit in LincFarm) that will be affected by the event. Table 3-6 shows a list of the management events, the ID and target mob or block.

**Table 3.6:** List of events identifiers, description and target group

ID	Description	Target group
1	Grazing rules	Mob
2	Shear	Mob
3	Cull	Mob
4	Castrate	Mob
5	Purchase animals	Mob
6	Sell animals	Mob
7	Move replacement	Mob
8	Flush	Mob
9	Tup	Mob
10	Wean	Mob
11	Feed hay	Mob
12	Close for hay	Block
13	Cut hay	Block
14	Sow crop	Block
15	Harvest crop	Block
16	Vaccinate	Mob
17	Drench	Mob
18	Dip	Mob
19	Hormone application	Mob
20	Crutch	Mob
21	Make block	Block
22	Kill block	Block
23	Animal inventory	Mob
24	Feed inventory	Hay barn
25	Join mobs	Mob
26	Split mobs	Mob

### 3.4.2.1. Block Events

This section describes the events listed in Table 3-6 using a sample illustration for events whose target is a block of land.

#### *Make and Destroy Block*

A block is created by listing the paddocks belonging to it. Illustration 1 shows two blocks being created on 1 January of year 1. Block 1 contain 6 (1, 8, 7, 3, 5 and 6) paddocks while block 2 contains 7 (2, 4, 9, 10, 11, 12 and 13). The NPdks variable informs the program of the number of paddocks to be read for each block being made. The hash sign (#) at the start of a line in an input file means the information contained in the line is a comment and thus not used by the model for simulation purposes.

```
# Make Blocks:
# Year      Date  Event  BlockID  NPdks  PaddockList
E 1         1     20     1        6     1 8 7 3 5 6
E 1         1     20     2        7     2 4 9 10 11 12 13
```

#### **Illustration 1:** Make block event

For a block to be created, it has first to be ‘killed’ so as to free paddocks as the event calendar acts as a circular list; which means that, as a new year starts, the blocks created the previous year must be destroyed, i.e. paddocks must be freed before new blocks can be

created. Therefore, destroy block events must precede the make block events.

```
#Destroy Blocks:
# Yr Date      Ev      BlockID
E 1   1        21       30
E 1   1        21       31
```

### **Illustration 2:** Destroy block event

The information contained in the `DestroyBlock` illustration requests the farm simulation model to destroy blocks 30 and 31 on 1 January. This results in the paddocks contained in the blocks being freed and thus becoming available to become part of other block(s).

### **Sow Crop event**

The sow crop event allows the manager to change the plant species growing in a paddock. While the area and aspect of a paddock are fixed, the plant species growing on the paddock can be changed through a `Sow Crop` event:

```
# Sow Crop:
# Yr Date  Event BlockID  Spc   Leaf  Stem  Root  TNC
E 1  60    13    31      1    50   50   0    0  sow grass
E 1  274   13    31      2     0    0   100  50  sow lucerne
```

### **Illustration 3:** Sow crop event

This example shows paddock 31 being sown with a mix of ryegrass-clover ( $Spc=1$ ) on day 60 of year 1 and later on day 274 of the same year the paddock is sown with lucerne ( $Spc=2$ ). The original version of `LincFarm` did not simulate the process of seed germination. However, due to the inclusion of annual ryegrass in this study, a germination routine has been included. Since the illustration given above is based on the original version of the model which did not simulate seed germination, initial amounts of leaf and stem (for grass) or root and total non-structural carbohydrate (TNC: for lucerne) had to be specified and must be greater than zero. When this event takes effect an entry is added to the accounting file.

### **Make and Cut Hay**

A ‘close for hay’ event ensures that there are no animals grazing on the block targeted to be closed from grazing for pasture accumulation. If there are animals on the block, the simulation stops and informs the user of the problem.

```
# Close block for hay:
# Yr Date      Event  BlockID
E 1  276        11      21

# Cut hay:
# Yr Date  Event Block  StbLeaf  StbStem  StbDead  Efficiency
E 1  309    12    21      50      250     0        0.8
```

### **Illustration 4:** Make and cut hay events respectively

The cut hay event will harvest the grass and/or forage and place it in the hay barn. The event requires information on the amount of leaf stubble (StbLeaf), stem (StbStem) and dead (StbDead) material left after cutting (harvesting). The Efficiency term indicates the efficiency of harvest. For instance, in the sample illustration above, 80.0% of the crop made it to the barn with 20.0% being considered waste. In the case of ryegrass-clover pastures, leaf stubble must be greater than zero otherwise the plant will cease growing. There is no such restriction for lucerne, within the model, as this plant uses carbohydrate reserves (TNC) to restore leaf mass following harvesting.

### ***Feed Inventory***

The feed inventory event applies to the hay barn by obtaining the amount of each feed species available in the barn on the day when the event occurs.

```
# Feed Inventory
# Yr   Date      Event   Target
E 1    250       23      0
```

#### **Illustration 5:** Feed inventory management event

Since the feed inventory event does not apply to any particular block, the value of target block is set to zero. In a scenario where more hay has been fed to the animals than the amount available in the barn, the feed inventory records a negative value implying hay has to be bought to cater for the difference. When this occurs the model component used for analyzing output (FarmEnd) adds a feed purchase entry into the accounting file.

### **3.4.2.2. Mob Events**

#### ***Grazing rules***

The grazing rules management event provides a platform for the control of the interaction between animals and plants by assigning a grazing block to a mob, determining how a block is split (into grazing breaks), and by indicating the rotation to be followed by the mob.

```
# Grazing Rules:
# Yr Date  Ev MobID   Sys  CompMob  BlockID  NBrks  Type  Crit
E 1  1     0  1       0    0       1     12   1     4
E 1  60    0  1       0    0       2     20   0    750
E 1  100   0  1       2    2       3     20   1     4
E 1  227   0  1       0    0       6     1    1    46
E 1  100   0  2       1    1       3     20   1     4
E 1  1     0  4       1    2       2     25   1     2
E 1  100   0  4       0    0       0     0    1     0
```

#### **Illustration 6:** Grazing rules

The grazing rule management event illustration sample shows a rotation followed by three mobs at different times of the year. The model is able to accommodate three grazing strategies with a mob grazing alone (`Sys=0`), leading another mob (`Sys=1; Leader`), or being followed by another mob (`Sys=2; Follower`). For the leader and follower systems, a companion mob (`CompMob`) must be indicated (mob 1 follows mob 2 between days 100 and 227 in the example above). The `NBrks` variable refers to the number of grazing breaks into which the block will be split— with electric fences for rotation purposes. If the variable is set to 1, then the mob is considered as being set stocked.

The grazing rotation can be defined in terms of minimum cover (`RotationType=0`) or days per break (`RotationType=1`). The criterion (`Crit`) for shifting animals to a new break depends on the rotation type. For instance, if `RotationType` is equal to zero then the criterion is in terms of minimum cover ( $\text{kg Green DM ha}^{-1}$ ) while if `RotationType` is equal to one then criterion for rotation is in days. A mob will follow the same rotation pattern until new grazing rules are assigned; if a full rotation has been completed and no new grazing rules are encountered then the rotation will start again. It is noteworthy that, if the rotation is of `RotationType` zero and the available green DM in the block is less than the set minimum cover, the gates will be opened and the animals will be set stocked until new grazing rules take effect.

A defined mob needs a place to stand at all times unless it has no animals. For example, if mob X is being fed grain (instead of grazing) for a period of time, it must still be assigned a block (through the grazing rules event) during this period. When a mob is emptied by sale or by being moved to another mob, its grazing rules should be cleared by setting zeros for the `BlockID`, `NBrks`, and `Crit` variables as shown by mob 4 on day 100 for the sample illustration above.

### ***Hay feeding***

The hay feeding event applies to all types of feed defined in the base definition file (BDF) and is thus not limited to hay feeding as the event name suggests. A hay feed activity can be achieved by either setting a proportion of hay available in the barn to be fed to a specific mob at specific date or as a proportion of the mob's energy requirements.

```
# Feed Hay:
# Yr Date Event MobID Spc PropReq HayProp MinHay NDays
E 1 152 10 5 1 1 0.3 0.2 92
E 1 152 10 1 1 0 0.8 0.3 92
E 1 152 10 2 1 0 1.0 0.2 75
```

**Illustration 7:** Feed hay event

The `SpC` variable refers to the species of feed to be offered, `NDays` is the number of days during which the feeding will occur (starting at `Date`), `PropReq` indicates whether feeding is expressed as a proportion of requirements. If `PropReq` is equal to 1, the feeding will be expressed as a proportion of mob's energy requirement or as a proportion of the amount available in the barn where the `PropReq` is equal to zero. The `HayProp` is the proportion of either requirements or hay available to be given daily, `MinHay` is a safety feature to avoid animal starvation. Where `PropReq` is equal to 1, `MinHay` is ignored. However, if `PropReq` is equal to 0 and the available hay in the barn is not enough to meet `MinHay` proportion of energy requirements, additional hay will be purchased automatically, fed and recorded in the accounting file.

When the `PropReq` equals 1, the model calculates mob energy requirements by adding up the energy requirements of all the animals in the mob. These requirements are converted to weight units (based on the energy content and digestibility of the feed), and the appropriate amount of hay is fed daily. However, when `PropReq` equals 0, the model multiplies `HayProp` by the amount of hay (of the given species) available in the barn and reserves the resulting amount for use by the target mob. The hay to be fed is taken out of the barn and placed in a reserved pool; therefore it is not available for use by other mobs. As the simulation runs, the model checks whether the amount of hay fed satisfies the set value of energy requirements for the mob requirements.

### ***Replace***

The replace management event is targeted at a mob on a farm and each mob can contain its own replacement policy which lists animal classes to be bought into the mob. The event determines when the actual replacement occurs and also determines whether culled animals are sold and/or shorn. The illustration below shows a sample of a replace management event.

```
# Replacement of Animals:
# Yr   Date  Event  MobID  SellCulls  ShearCulls
E 1    60    6      1      1          0
E 1    311   6      2      0          0
```

### **Illustration 8: Replacement of animals**

In this illustration, the replacement policy for mob 1 will be executed on day 60, the heavier ewes will be kept and the culls will be sold (`SellCulls=1`) without being shorn (`ShearCulls=0`). The replacement policy for mob 2 will be executed on day 311 whereby the culled animals will neither be sold nor shorn. When `SellCulls` variable is set to zero, the culled animals (including animals not used for replacement) are returned to their original

mob, for example when ewe lambs are moved into a replacement mob by selecting heavier animals and returning the remaining animals to the lamb mob to be fattened.

### ***Purchase***

A purchase event is similar to the replace event, it informs a target mob to execute its previously defined purchase policy. The illustration shown below presents a purchase management event. On day 60 a ram purchase event is executed and the rams bought are moved to mob 9 which in the current context was considered to be the ram mob.

```
# Animal purchase:
# Yr   Date   Event  MobID
E 1    60     4      9
```

**Illustration 9:** Animal purchase

### ***Cull***

Culling is expressed as a proportion of the existing animals of a given year class (YearClass) in a specific mob (ModID). A minimum number of animals to be kept can be specified in order to avoid culling animals after bad years characterized by high stock mortality requiring a subsequent stock numbers to be rebuilt.

```
# Cull mobs:
# Yr Date   Event  MobID   Sex   Prop  YearClass  Min  ShearCulls
E 1  330    2      1       2    1.0   6         0    0
E 1  330    2      1       2    0.05  5        112  0
```

**Illustration 10:** Mob culling event

In this sample illustration, animals from mob 1 will be culled on day 330 and all the aged ewes (year class 6) sold (Prop=1.0, Min=0); while only 5.0% of the 5 year class ewes will be sold, with the provision that at least 112 animals must be retained. Therefore, if mob 1 contains less than 112 5-year old ewes (on day 330), no culling will occur in this group. Culls can be shorn before being sold, however no shearing is set in this sample meaning culls are sold without shearing.

### ***Flushing and tugging***

In the LincFarm model, ewes can be flushed prior to mating by using the flush event. The event does not have any effect on the amount of feed and/or pasture fed to the ewes. This is captured when setting grazing rules by allowing a bigger grazing area during the flushing period or by allocating ewes more feed via the feed hay event.

```
# Flush:
# Yr   Date   Event  MobID
E 1    61     7      1
```

**Illustration 11:** Ewe flushing

This event stores the LW of the animals in the target mob which is later compared with the weight at mating. The dynamic effect on multiple ovulation can then be estimated as described in section 3.3.1 above. The actual length of flushing is determined by the spread between the flush and tup events.

### ***Tup***

Mating is triggered by a tup event which contains the sire breed (SBreed), mating treatment (Trt: 0=autumn, 1=spring), the ram mob (RMob), the length of tugging (Lgth in days) and the ewe to ram ratio (E/R).

```
# Tup:
# Yr Date Event MobID SBreed Trt RMob Lgth E/R
E 1 76 8 1 1 0 9 60 80
```

#### **Illustration 12: Tup event**

As shown in this sample illustration, when the tup event is encountered, the appropriate number of rams are moved from the ram mob (9) into the ewe mob (1) and kept there for 60 (Lgth) days. The mating treatment is used for out-of-season lamb production situations. If the mating treatment is equal to one, the probability of multiple ovulation will be decreased and hormone will be used to stimulate cycling. In such a scenario, the hormone treatment is recorded in the accounting file.

### ***Weaning***

The date of mating and length of gestation for the given animal species will determine the lambing date. Lambs remain with ewes until a weaning event occurs as shown in the sample weaning event illustration sample shown below.

```
# Wean:
# Yr Date Event MobID LmbMob
E 1 310 9 1 4
```

#### **Illustration 13: Wean event**

From this sample, all lambs will be moved from mob 1 into mob 4. The lambs will automatically change status from suckling to weaned lambs while ewes from which the lambs have been weaned will change status from lactating to dry ewes. The program will warn you if lambs have not been weaned when ewes reach the end of their lactation period.

### ***Lamb sale***

The program is set such that animals to be sold can be selected based on sex and EBW.

```

# Lamb Sales:
# Yr   Date   Event   MobID   MinBW   Sex   Shear
E 1    330     5       4       30      1     0
E 1    360     5       4       30      1     0

```

**Illustration 14:** Lamb sale event

In this illustration, all the ram lambs ( $Sex=1$ ) from mob 4 whose EBW is 30.0 kg or greater are being sold on either day 330 or 360. The program establishes the current EBW of the ram lambs at the two dates and sells all those that are greater or equal to 30.0 kg. The sale lambs are not being shorn ( $Shear=0$ ) before sale.

Upon sale, the normal distribution which represents a group of animals is truncated at  $MinBW$ , and the lower end of the distribution is kept on the farm. To sell all the lambs,  $MinBW$  is set to zero. The sale animals can be moved into an independent mob prior to sale using split mob event. If sale animals are shorn before disposal, the shearing expenses and wool sale are recorded in the accounting file.

**Animal inventory**

The animal inventory event results in all the animals on the farm being counted (by species, breed, sex and age) and written to the accounting file. The inventory is taken only once a year and mostly occurs during winter when lambs are off the farm.

```

# Animal inventory:
# Yr   Date   Event   MobID
E 1    182     22     0

```

**Illustration 15:** Animal inventory

The animal inventory is not applied to a particular mob, but rather to the whole farm requiring that mob identifier to be set to zero ( $MobID=0$ ).

**Shearing**

The shear management event indicates the mob to be shorn. It sets the wool on each animal to zero and writes the number of animals and total wool clip to the accounting file.

```

# Shear:
# Yr   Date   Event   MobID
E 1    210     1       1
E 1    210     1       2

```

**Illustration 16:** Shear event

**Health events**

There are three main health events which include vaccinate, drench and dip. The model assumes all the animals to have normal health at all times thus the presence of the events does not affect the simulation. Their only role is to write an entry into the accounting file with the number of animals processed to maintain a correct record of operating expenses.

```

# Vaccinate:
# Yr   Date      Event      MobID
E 1    210        15         1
E 1    210        15         2

# Drench:
# Yr   Date      Event      MobID
E 1    230        16         1
E 1    152        16         2
Pre-Lamb Drench
Hoggets

# Dip:
# Yr   Date      Event      MobID
E 1    210        17         1
E 1    210        17         2

```

**Illustration 17:** Vaccinate, drench and dip events respectively

### *Split and join mobs*

A high degree of control in animal management can be achieved by splitting and/or joining mobs. Mobs can be split by four criteria as indicated by the criterion key (`Crit`): (i) sex = 0, (ii) reproductive status = 1, (iii) age (days) = 2, and (iv) EBW = 3. The following sample illustration shows the split mobs event based on sex, reproductive status, age, and EBW respectively. In the first case, ewes (`Crit=0; Cval=2`) are moved from mob 1 into 2. Since `Crit= 0, Cval = 2` refers to sex (2 = ewes).

```

# Split mobs (Sex):
# Yr   Date  Event  MobID  DestMob  Crit  CVal
E 1    270   25     1       2         0    2

```

**Illustration 18:** Split mobs event

Since the `Crit` variable is set to 1 in the sample illustration given below, then the `Cval` variable bases its split mob event on the reproductive status of the female animals. The three possible statuses are dry, pregnant and lactating whose identifier index numbers are 0, 1 and 2 respectively. In this sample, dry ewes (`Cval=0`) are moved from mob 1 to 2.

```

# Split mobs (Reproductive status):
# Yr   Date  Event  MobID  DestMob  Crit  CVal
E 1    121   25     1       2         1    0

```

**Illustration 19:** Split mobs by reproductive status event

Splitting mobs based on age results in `Crit` variable being set to 2 in which case the `Cval` variable refers to age in days. There is also an introduction of an additional variable (`MoveTop`) as a result of using age as split and join mob event criterion. The variable is either set to 0 (false) or 1 (true).

```

# Split mobs (Age):
# Yr Date  Event  MobID  DestMob  Crit  CVal  MoveTop
E 1  180   25     2       9         2   365    1
E 1  198   25     2       9         2   365    0

```

**Illustration 20:** Split mobs by age event

This sample illustration means older or younger animals are moved from mob 2 into 9 with the first line of the sample informing the program to move all the animals whose age is greater than or equal to 365 days from mob 2 to 9. The second program line moves animals under 365 days old from mob 2 to 9.

Finally animals can be split based on EBW as shown in the illustration below. The variable `Crit` is set to 3 with variable `CVal` referring to EBW. In this sample heavy animals are moved from mob 2 into 9.

```
# Split mobs (EBW):
# Yr   Date  Event MobID   DestMob Crit  CVal   MoveTop?
E 1    180   25    2         9      3    45     1
```

**Illustration 21:** Split mobs by EBW event

Since `Crit=3` then `CVal` refers to EBW, notice that `CVal` must be a whole number (i.e. 45.2 is invalid). Lighter animals in a mob could be moved by setting `MoveTop` to zero.

Two mobs can be combined using a join mobs event. This event makes the programme move all the animals from the source mob (`SrcMob`) into the destination mob. This event will move all the animals from mob 9 into 2 leaving the source mob empty.

```
# Join mobs:
# Yr   Date   Event  MobID   SrcMob
E 1    180    24     2       9
```

**Illustration 22:** Join mobs of animals

### 3.4.3. Paddock Records

A paddock record contains a number identifying the paddock, corresponding area in hectares, a secondary list of pasture sectors and a sampling record. The list of pasture sectors stores one or more elements containing the amount of leaf, stem and dead material in kg DM ha<sup>-1</sup> and the proportion of the paddock that the pasture sector constitutes. Both the pasture growth and animal intake aspects are simulated at sector level. Cacho *et al.* (1995) describes the importance of separating data in pasture sectors.

### 3.4.4. Block Records

A block consists of one or more paddocks, which can be split into grazing breaks or reserved to produce hay. It is at block level that paddock management occurs. Considering that the blocks and breaks are the management units, grazing is not limited to paddock boundaries but rather to the area available following opening block or break gates and using electric fences. Following implementation of make block event (see illustration 1), the newly created block moves its selected paddocks pointer from the available paddocks list to its

paddock list. This ensures that no paddock is assigned to more than one block simultaneously.

When a block is selected for grazing, the relevant paddocks are split into sectors to obtain the required number of grazing breaks. As shown in Figure 3-3, a break is responsible for connecting animals and pastures in a block and each contains a reference sector list which shows individual pasture sectors temporarily grouped together for grazing. It is possible for a break to contain sectors from different paddocks by keeping gates open or part of a paddock which has been electrically fenced (Cacho *et al.* 1995). Each grazing break updates herbage mass in its component pasture sectors in response to animal intake for the simulated day.

#### **3.4.5. Mob Records**

A mob defines a group of animals grazed together and is considered as a single management unit and maintained as a distinct entity throughout the simulation run. The mob record contains its identification number, a series of secondary animal lists (groups) classified by age and sex, grazing, hay and sampling records. The movement of a mob in a farm is controlled by the grazing rules. The rules guiding the movement can be based on time (number of days per break) or residual cover. Details on grazing rules are presented in Cacho *et al.* (1995). A hay record contains information on the time period in which hay will be fed, the amount of hay available for the mob in the period defined, a test (Boolean variable; true or false) indicating whether the available hay will be fed depending on a target proportion of animal energy requirements or in relation to the amount of hay available, and a variable indicating the proportion to be offered each day. If the amount of hay available is less than the amount needed (based on animal energy requirements) to compensate the target energy requirement gap, hay is purchased.

Each record in the animal list represents a group of animals of the same breed, sex, age and reproductive status with body weight for animals in a group being assumed to conform to truncated normal distribution, with upper and lower bounds expressed on standard deviations about the mean. An animal record which refers to a single, or multiple animals of the same sex, age and reproductive status can be moved between mobs. The reproductive status of ewes is given by a variant portion in an animal record. The variant contains information on sire breed and number of foetuses in pregnant ewes, and milk production and location of suckling lambs for lactating ewes. Information in animal records can be split and/or combined. For instance, if the status of some animals present in a particular record changes, then the record can be split or combined and the number of animals in the group to which the animals have moved to or from adjusted to reflect the altered situation.

### **3.5. Sampling Records**

These records are present in the paddock and pasture sector, mob, and animal data structures. These records store cumulative values of rate processes like leaf growth and the mean values of state variables such as green dry matter. Information in these records is updated daily and means calculated on the basis of the output interval requested by the experiment file.

### **3.6. Model Input and Output Data Files**

#### **3.6.1. Model Input Files**

The LincFarm model contains a number of data files designed to define the farm; the pastures, animals and management on the farm; and the experimental treatments to be simulated. The following is a list of the main input files with a summary of the data contained in each.

##### ***Base Definitions (\*.BDF)***

This file contains the basic animal and plant definitions. It details the species available and contains data on the energy content of plants and feeds and digestibility of each plant and/or feed.

##### ***Animal Parameters (\*.APF)***

The \*.APF file contains parameter values for the animals described in the \*.BDF file. These parameters are used internally by the equations which represent the behaviour and/or performance of the animals. Currently sheep may be defined as one of three "types" - meat, wool or dual purpose - and data for each type are contained in the file.

##### ***Plant Growth Parameters (\*.PGP)***

The \*.PGP file contains parameter values for the plant species described in the \*.BDF file. These parameters represent the average growth potential, senescence and decay rates for each species, cultivar or mix in the environment being simulated. The parameters change seasonally and they can be viewed as a calendar of parameter values. Plant growth parameters may be defined at any interval; currently they are defined at two weekly intervals.

##### ***Experiment (\*.EXP)***

The \*.EXP file contains the experimental design; it includes experimental duration (years), sampling intervals and variables to be altered and their values.

##### ***Farm Description (\*.FDF)***

The \*.FDF file contains a description of the farm being simulated, including the number and types of mobs, the numbers and class of animals, the number, size and pasture type of paddocks, whether these are separated into management blocks, and a complete calendar of management events.

#### ***Dynamic Management System (\*.DMS)***

The \*.DMS was not originally required to run the model and has been included following development of the Destocking and Marketing Algorithm for this study (described in Chapter 6). The input files contain tests (and target test values) to evaluate the feed demand and supply profile on the farm and appropriate actions designed to destock the farm based on current and/or projected feed scarcity, a combination of feed available at the time, and the probability of receiving enough rainfall to support sufficient pasture growth in a defined period into the future.

#### **3.6.2. Model Output Files**

Results from model runs are placed in three output files for subsequent analysis, two of which (\*.MOB and \*.PDK) contain physical information relating to animal and paddock status and a third (\*.ACT) which contains economic information.

##### ***Mob file (\*.MOB)***

The mob file contains the state of the animals in each mob—that is, weight, protein, fat, and energy consumed at sampling intervals as requested by the experiment file.

##### ***Paddock file (\*.PDK)***

The paddock file contains information on the state of each paddock in terms of variables such as green dry matter and pasture growth at sampling intervals as requested by the experiment file.

##### ***Accounting file (\*.ACT)***

The accounting file contains every transaction which was executed during the simulation, such examples as wool and animal sales, hay harvest and purchases records, and number of animals shorn.

#### **3.6.3. LincFarm Model Extension**

The original LincFarm model was extended by including annual ryegrass, cocksfoot and lucerne pasture types, a thermal time (Tt) based forage crop model used to simulate DM

accumulation for winter and summer crops as presented in Chapter 4, a beef growth and composition model described in Chapter 5 and a destocking and marketing algorithm used in simulating potential tactical adjustments in response to climatic variability under high performance dryland sheep systems described in Chapter 6.

## CHAPTER 4

### Pasture Growth Sub-models

#### 4.0. Introduction

This chapter presents the mechanistic pasture growth model parameters and the procedure used in obtaining, evaluating and setting them to suitably describe additional pasture species (annual ryegrass, cocksfoot and lucerne) included in the extended LincFarm model. In addition, an evaluation of the performance of a thermal time ( $T_t$ ) based forage crop model used to simulate DM accumulation for winter and summer crops is presented.

The mechanistic pasture growth model which is a revision of the Woodward (1998) and Woodward *et al.* (1998) pasture growth model of Bywater *et al.* (1999) was used in this study. The modifications applied by Bywater *et al.* (1999) are described in the previous chapter (Chapter 3). The model has been parameterised for perennial ryegrass, white and red clovers, tall fescue and chicory for use in simulating grazing sheep systems. However, to evaluate alternative risk management strategies considered in this study, there is need to incorporate annual ryegrass, cocksfoot and lucerne as these pasture types were used as source of animal feed in the farm trials used as a basis for this analysis. These additional pasture types were accommodated within the existing Bywater *et al.* (1999) mechanistic plant model. However, this requires estimates of the parameters presented in Table 4-1.

#### 4.1. Setting Model Parameters

The pasture specific parameter file for annual ryegrass and cocksfoot contains a total of 46 parameters each (see Table 4-1) while lucerne has an additional 9 parameters used in the root model (see Table 4-4).

**Table 4.1:** Parameters estimates for cocksfoot and annual ryegrass

Parameter number	Parameter	Description <sup>1</sup>	Pasture type		Units	Sources <sup>2,c,ar</sup>
			Cocksfoot	Annual ryegrass		
<b>Growth model parameter</b>						
1	GV[gv_Y]	efficiency of converting substrate to structure (3:12)	0.75	0.76	mgCO <sub>2</sub> (kgDMha <sup>-1</sup> ) <sup>-1</sup>	Woodward <i>et al.</i> (1998) <sup>c, ar</sup> , Hansen and Jensen (1977) <sup>ar</sup>
2	GV[gv_pieV]	assimilate partition to vegetative growth (3:17)	0.60	0.60	mgCO <sub>2</sub> m <sup>-2</sup>	Johnson <i>et al.</i> (1995) <sup>c</sup> ; Ryle 1970 <sup>ar</sup>
3	GV[gv_pieR]	assimilate partition to reproductive leaf (3:17)	0.66	0.67	"	Woodward (1997) <sup>c</sup> ; Ryle (1970) <sup>ar</sup> Liang <i>et al.</i> (2002) <sup>ar</sup>
4	GV[gv_pieS]	assimilate partition to reproductive stem (3:17)	0.3	0.26	"	Woodward (1997) <sup>c</sup> ; Ryle (1970)
5	GV[gv_pieL]	assimilate partition to root (3:17)	0.68	0.68	"	
6	GV[gv_gamma]	conversion from kgDMha <sup>-1</sup> to mgCO <sub>2</sub> m <sup>-2</sup> mass (3:12)	161	161	mgCO <sub>2</sub> (kgDMha <sup>-1</sup> ) <sup>-1</sup>	Woodward <i>et al.</i> (1998) <sup>c, ar</sup>
7	GV[gv_R]	target mass	1.0	1.0		
8	GV[gv_deltaE]	worm removal constant (3:57)	0.0005	0.0005		Woodward (1997) <sup>c, ar</sup>
9	GV[gv_deltaD]	base decomposition rate (3:56)	0.0148	0.0148	kg ha <sup>-1</sup> d <sup>-1</sup>	Andrew (2009) <sup>c, ar</sup>
10	GV[gv_sigma]	leaf senescence rate (3:14)	0.0011	0.0012	kg ha <sup>-1</sup> d <sup>-1</sup>	Woodward <i>et al.</i> (1998) <sup>c</sup> , Lemaire and Agnusdei(2000) <sup>ar</sup>
11	GV[gv_R <sub>m1</sub> ]	dark respiration (3:13)	1.72	1.6	mgCO <sub>2</sub> g <sup>-1</sup> h <sup>-1</sup>	Andrew (2009) <sup>c</sup> , Ludlow (1985) <sup>ar</sup>
12	GV[gv_R <sub>m2</sub> ]	leaf respiration (3:13)	0.08	0.061	mgCO <sub>2</sub> g <sup>-1</sup> h <sup>-1</sup>	Andrew (2009) <sup>c</sup> , Hansen and Jensen (1977) <sup>ar</sup>
13	GV[gv_stress1]	water stress lower limit (3:27)	-2.2	-2.5	Mpa	Garrier and Roy (1988) <sup>c</sup> , Durand <i>et al.</i> (1997) <sup>ar</sup>
14	GV[gv_stress2]	water stress upper limit (3:36)	-0.2	-0.5	Mpa	" "
<b>Photosynthesis model parameter</b>						
15	Q	maximum photosynthesis at reference temperature (3:7)	1.17	0.82	mgCO <sub>2</sub> m <sup>-2</sup> (leaf)s <sup>-1</sup>	Woodward (1997) <sup>c</sup> , Hansen and Jensen (1977) <sup>ar</sup> Sheehy and Peacock (1975) <sup>c</sup>
16	T <sub>ref</sub>	optimal temperature (3:7)	21	20	°C	Hamid-Auda <i>et al.</i> (1966) <sup>c</sup> , Weisner and Grabe (1972) <sup>ar</sup> Taylor <i>et al.</i> (1968), Rapacz <i>et al.</i> (2007) <sup>ar</sup> , Musil <i>et al.</i> (2009) <sup>ar</sup>

Parameter number	Parameter	Description <sup>1</sup>	Pasture type		Units	Sources <sup>2,c,ar</sup>
			Cocksfoot	Annual ryegrass		
17	T <sub>0</sub>	half optimal temperature (3:7)	1.0	1.0	°C	Woodward <i>et al.</i> (1998) <sup>c, ar</sup>
18	alpha	peak leaf photosynthesis efficiency (3:7)	0.01	0.076	mgCO <sub>2</sub> J <sup>-1</sup>	Johnson <i>et al.</i> (1995) <sup>c</sup> , Liang <i>et al.</i> (2002) <sup>ar</sup>
19	theta	curvature parameter in leaf photosynthesis response (3:7)	0.81	0.86	dimensionless	Woodward <i>et al.</i> (2002) <sup>c</sup> ; Thornley and Johnson (2000) <sup>c</sup>
<b>Reproduction model parameters</b>						
20	A	minimum sustainable SLA (3:10)	0.0075	0.04	m <sup>-2</sup> (leaf) (ground)	m <sup>2</sup> Andrew (2009) <sup>c</sup> , Tanaka (1976) <sup>ar</sup>
21	B	difference between A and SLA when grown in the dark (3:10)	-0.001	-0.078	"	Andrew (2009) <sup>c</sup>
22	C	instantaneous rate of change of SLA (3:10)	0.1661	0.165	"	Andrew (2009) <sup>c</sup> , Lötscher <i>et al.</i> (2003) <sup>ar</sup>
23	m	rate of stem maturation	0.09	0.09	mgCO <sub>2</sub> m <sup>-2</sup> (ground) d <sup>-1</sup>	Woodward (1998) <sup>c, ar</sup>
24	flg	flag leaf fraction of the total reproductive leaf (3:12)	0.21	0.21		Andrew (2009) <sup>c, ar</sup>
25	t1	day when stem elongation start	273	282	days	Peri (2002) <sup>c</sup> , Kathryn <i>et al.</i> (2004) <sup>ar</sup>
26	t2	day when stem maturation starts – day of ear emergence	306	296	days	" "
27	t3	day when stem senescence starts	324	315	days	" "
28	t4	day when stem elongation ceases	333	324	days	" "
<b>Light capture model parameters</b>						
29	k	extinction coefficient (3:3, 3:11)	0.44	0.63	m <sup>-2</sup> (ground) (leaf)	m <sup>2</sup> Hamid-Auda <i>et al.</i> (1966) <sup>c</sup> , Sheehy and Chapas (1976) <sup>ar</sup> , Ludlow (1985) <sup>ar</sup>
30	kv	extinction coefficient vegetative leaf (3:49, 3:50)	0.88	0.88	"	
31	kr	extinction coefficient reproductive leaf (3:49, 3:50)	0.92	0.92	"	
32	km	extinction coefficient reproductive stem (3:49, 3:50)	0.92	0.92	"	
33	epsilon	reproductive leaf elevation	0.0008	0.0011	kgDM ha <sup>-1</sup>	Woodward (1997) <sup>c</sup>
34	c <sub>m</sub>	light capture efficiency of mature stem (3:3, 3:12)	0.003	0.003	ha kgDM <sup>-1</sup>	Thornley and Johnson (2000) <sup>c, ar</sup>
35	c <sub>d</sub>	light capture efficiency of leaf, sheath and dead material (3:3, 3:12)	0.009	0.009	"	"

Parameter number	Parameter	Description <sup>1</sup>	Pasture type		Units	Sources <sup>2,c,ar</sup>
			Cocksfoot	Annual ryegrass		
36	c <sub>mr</sub>	light capture efficiency of reproductive stem and leaf (3:3, 3:12)	0.00046	0.00046	"	
37	w <sub>d</sub>	proportion of dead material in mixed layer	0.28	0.28	kgDM ha <sup>-1</sup>	Thornley and Johnson (2000) <sup>c, ar</sup> , Woodward <i>et al.</i> (2002) <sup>c, ar</sup>
<b>Specific leaf area</b>						
38	minSLA	leaf area ratio of vegetative green (3:9)	0.0019	0.00186	ha (leaf) kgDM <sup>-1</sup>	Woodward (1997) <sup>c</sup> , Ludlow (1985) <sup>ar</sup>
39	invCoff	inverse coefficient (SLAc) (3:11)	0.133	0.165		Peacock (1975) <sup>ar</sup>
40	sigA	leaf lifespan (SigA) (3:54)	0.00057	0.00038	days	Woodward <i>et al.</i> (2002) <sup>c</sup> , Lemaire and Agnusdei(2000) <sup>ar</sup>
41	sigB	leaf lifespan (SigB) (3:54)	0.0074	0.0072	days	Lemaire and Agnusdei(2000) <sup>ar</sup>
<b>Assimilate model parameters</b>						
42	Cubic	current day of the year	10	102	days	Peri (2002) <sup>c</sup> , Lemaire and Agnusdei(2000) <sup>ar</sup>
43	Quad	reference day	80	249	"	Lemaire and Agnusdei(2000) <sup>ar</sup>
44	Linear	Percent	0.80	0.66	percent	Peri (2002) <sup>c</sup>
45	Const	Percent	0.50	0.88	"	Peri (2002) <sup>c</sup>

<sup>1</sup>Equation where the parameter appears in bracket

<sup>2</sup>Parameter values obtained from literature search

<sup>ar</sup>annual ryegrass

<sup>c</sup>cocksfoot

#### 4.1.1. Parameter Estimates Obtained from Literature Search

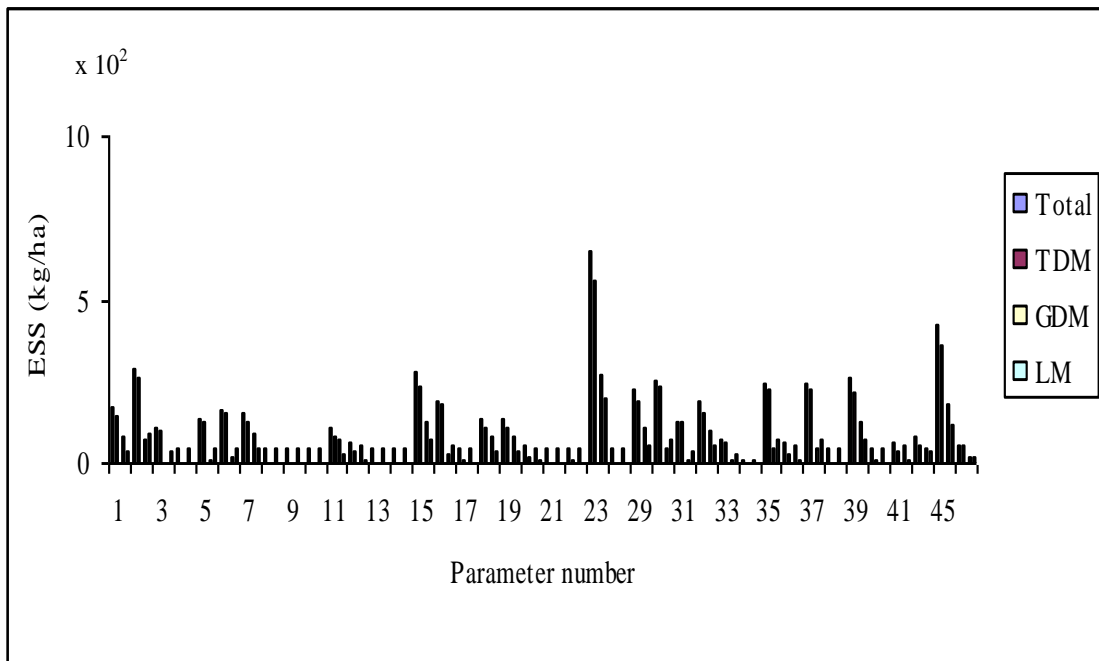
Table 4-1 presents parameters estimates for cocksfoot and annual ryegrass obtained from the literature search. It was assumed that site-specific soil and radiation moisture parameters did not change. They are described in section 3.1.3 and are presented in Tables 3-1 and 3-2.

#### 4.1.2. Preliminary Analysis

Sensitivity analysis of total dry matter (TDM), green dry matter (GDM), leaf matter (LM), and their total sum (Total) to independent changes in parameters presented in Table 4-1 were evaluated. These parameters occur in growth, photosynthesis, reproduction, light capture, specific leaf area and assimilate sub-models of the mechanistic plant growth model described by Bywater *et al.* (1999). Out of the 46 parameters in the sub-models, six (parameter numbers 25, 26, 27, 28, 42 and 43) were not varied as they were considered constants. They represented specific days in the plant growth process. Each of the other remaining parameters was varied by a constant multiplier ( $c$ ) of a value of 0.9 during a preliminary analysis and then for a range of values of  $c$  between 0.4 and 2.0 for parameters which showed significant response in the preliminary analysis. Each varied parameter was tested by running the model for a period of ten years. From each run, daily output of TDM, GDM and LM in kg DM ha<sup>-1</sup> were obtained for a parameter set where one of the parameters had been changed compared to the original set. These output estimates formed the basis against which parameter perturbation was carried out and error sum of squares (ESS) estimated for each combination of parameters. The ESS is given by:

$$ESS_i = \sum_{1}^n (\text{actual} - \text{predicted})^2 \quad (4:1)$$

where  $n$  is the number of pairs of output value (3650 for ten years run), actual is a vector of output values for parameter  $i$  at value  $i \times c$ , predicted is a vector of output values when all parameters are at base line value and  $c$  is a value of the parameter multiplier. The resultant ESS values for TDM, GDM, LM and their summed ESS for each parameter value when multiplied with 0.9 ( $c$ ) are shown in Figure 4-1.



**Figure 4-1:** Histogram of the ESS for TDM, GDM, LM and the summed ESS of the three components for each parameter value when that parameter value is 0.9 of the base line value for cocksfoot

Calculated parameters whose variation resulted in significant change in TDM, GDM, LM and their summed ESS were considered for optimization. Generally, parameter numbers 4, 8, 9, 10, 13, 14, 24, 34 and 38 resulted in zero ESS values for TDM and LM while parameter numbers 17, 20, 22, 36 and 40 varied marginally as shown in Figure 4-1. Based on results from this preliminary analysis, a total of twenty four parameters presented in Table 4-2 were selected for further analysis to establish their optimal values and/or range of optimal values.

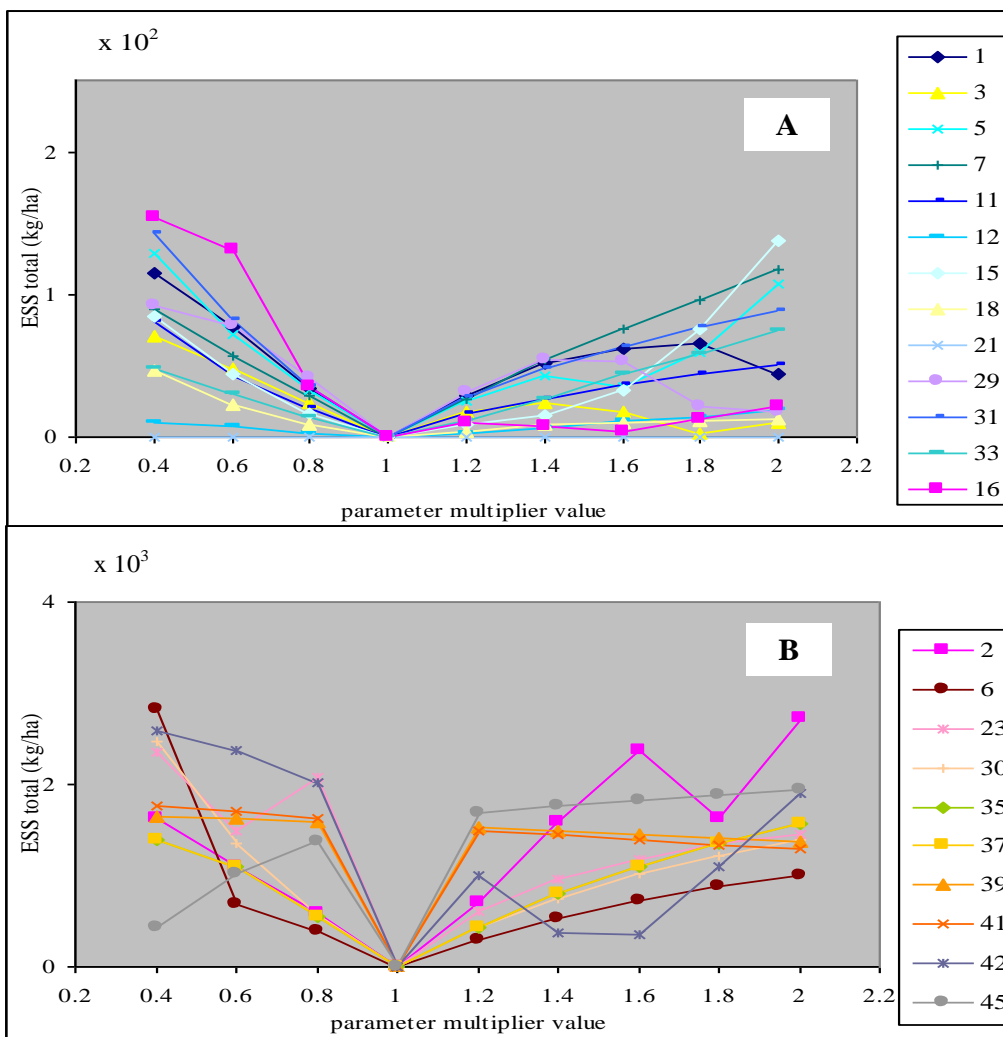
**Table 4.2:** Parameters within the pasture model with considerable influence on ESS for TDM, GDM, LM, and the sum of their ESS for ryegrass and cocksfoot

Parameter number	Parameter	Description	Pasture type	
			Cocksfoot	Annual ryegrass
<b>Growth model parameter</b>				
1	GV[gv_Y]	efficiency of converting substrate to structure	0.75	0.76
2	GV[gv_pieV]	assimilate partition to vegetative growth	0.60	0.60
3	GV[gv_pieR]	assimilate partition to reproductive leaf	0.66	0.63
5	GV[gv_pieL]	assimilate partition to the root	0.68	0.68
6	GV[gv_gamma]	conversion from kgDMha <sup>-1</sup> to mgCO <sub>2</sub> m <sup>-2</sup> mass	161	161
7	GV[gv_R]	set mass	1.0	1.0
11	GV[gv_R <sub>m1</sub> ]	dark respiration	1.72	1.6
12	GV[gv_R <sub>m2</sub> ]	leaf respiration	0.08	0.061
<b>Photosynthesis model parameter</b>				
15	Q	maximum photosynthesis at reference temperature	1.17	0.82
16	T <sub>ref</sub>	optimal temperature	21	20
18	alpha	peak leaf photosynthesis efficiency	0.01	0.076
<b>Reproduction model parameters</b>				
21	B	difference between A and SLA when grown in the dark	-0.001	-0.078
23	m	rate of stem maturation	0.09	0.09
<b>Light capture model parameters</b>				
29	k	extinction coefficient	0.44	0.67
30	kv	extinction coefficient vegetative leaf	0.88	0.88
31	kr	extinction coefficient reproductive leaf	0.92	0.92
32	km	extinction coefficient reproductive stem	0.92	0.92
33	epsilon	reproductive leaf elevation	0.0008	0.0011
35	c <sub>d</sub>	light capture efficiency of leaf, sheath and dead material	0.009	0.009
37	w <sub>d</sub>	proportion of dead material in mixed layer	0.28	0.28
<b>Specific leaf area</b>				
39	invCoff	inverse coefficient (SLAc)	0.133	0.165
41	sigB	leaf lifespan (SigB)	0.0074	0.0072
<b>Assimilate model parameters</b>				
44	Linear	percent	0.80	0.66
45	Const	percent	0.50	0.88

#### 4.1.3. Second Stage Analysis

This was achieved by re-running the program as previously described in section 4.1.2 but with the parameter multiplier ranging between 0.4 and 2.0 for the twenty four parameters presented in Table 4-2. Parameter 19 (curvature parameter in leaf photosynthesis response) was not varied as it is geometric in nature as opposed to assuming linear variation (0.4 to 2.0). In all cases, program runs were obtained utilizing parameters presented in Table 4-1.

Figure 4-2 shows total ESS of TDM, GDM and LM for sensitive parameters as the parameter values were changed. Varying parameters 12 and 21 over the multiplier range did not result in significant change in ESS. This indicates that the model is relatively less sensitive to the values of these parameters. The remaining parameters resulted in considerably marked U or V shaped curves signifying a moderate to high degree of model sensitivity to the value of the parameters. Because the model is sensitive to these parameters, it is important that their values are carefully defined; biological meaning (Peri *et al.*, 2005), literature support (Koots *et al.*, 1994), accuracy of parameter measurement (for example the optimal temperature for peak photosynthesis) and expert opinions (published and unpublished) was used in setting these parameters.



**Figure 4-2:** Total ESS of TDM, GDM and LM for moderately (A) and highly (B) sensitive parameters as this parameter value changes

#### 4.2. Choice of Parameter Set for Simulating Cocksfoot and Annual Ryegrass Growth

Following the second stage analysis whose results are presented in Figure 4-2, further information was obtained in the form of expert opinion (pers. com, D.J, Moot, Lincoln

University) and from the literature (Skinner *et al.* 2008; Peri *et al.*, 2005; Peri *et al.*, 2002; Woodward, 1998; Woodward *et al.*, 1998) in selecting parameter sets suitable to simulate cocksfoot and annual ryegrass growth and productivity. This led to the conclusion that it would not be appropriate to significantly vary parameters obtained from literature search (see Table 4-1) in the exception of moderate variation of the parameters used in the photosynthesis sub-model since net leaf photosynthesis is the driver of plant growth in simulation models (Peri *et al.* 2002). It is notable that the Bywater *et al.* (1999) model is moderately (parameter 15) and/or marginally (parameter 16 and 18) sensitive to changes in parameters used in the photosynthesis sub-model. As shown in Figure 4-2, parameters 16 and 18 show ESS curves that flatten out (are insensitive) above their optimum values.

In related species such as grasses, differences in parameters controlling response to the main environmental variables rather than the entire parameter set describing pasture species in plant growth simulation models influence their net leaf photosynthesis and subsequent productivity (Peri *et al.*, 2005). For annual ryegrass and/or cocksfoot in ambient [CO]<sub>2</sub> conditions, the main determinants of growth are temperature, water (Radcliffe and Baars, 1987; Moloney, 1991; Barker *et al.*, 1993) and nitrogen status (Donohue *et al.*, 1981; Moloney *et al.*, 1993; Peri *et al.*, 2001).

Mitchell and Lucas (1962) and Eagles (1967) reported an optimum temperature for photosynthesis for cocksfoot of 20.0-22.0°C. The value utilised in this study was 21.0°C obtained from a study by Taylor *et al.* (1968) while peak leaf photosynthesis efficiency (parameter 18) of 0.01 obtained from Johnson *et al.* (1995) compares well with the highest value recommended by Peri *et al.* (2005) of 0.0069. Peri *et al.* (2005) reported a decrease in peak leaf photosynthesis efficiency ( $\alpha$ ) of 2.8% per °C from 24.0 to 31.0 °C. The value was higher than reported by Thornley (1998) for grassland system of 1.5% per °C at temperatures above 15.0 °C but lower than the value obtained by Ku and Edwards (1978) of 8.0% for  $\alpha$  in wheat for temperatures increasing from 15 to 25.0 °C. The differences in these responses are attributable to species differences in the photorespiration response of C<sub>3</sub> grasses (Ehleringer and Björkman, 1977; Ehleringer and Pearcy, 1983).

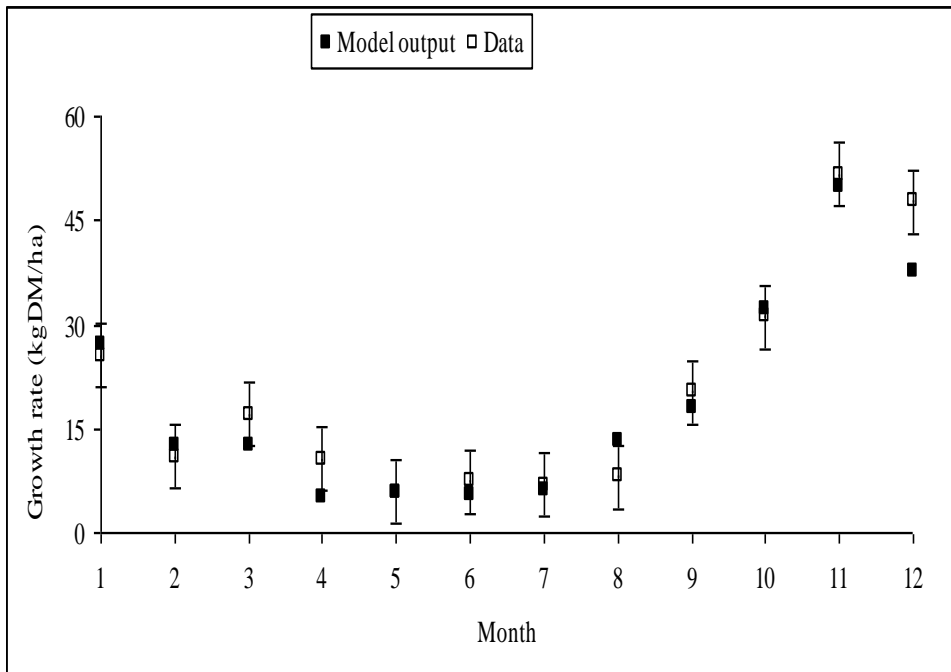
A negative linear relationship between  $\alpha$  and water stress of the plant was observed in severe water stressed situations as described in Peri *et al.* (2005). Peak leaf photosynthesis efficiency decreased by 29.0% from a water stress of -1.0 Mpa to the maximum pre-dawn leaf water stress measured at -1.6 Mpa. A value of -2.2 Mpa from Garrier and Roy (1988), at which  $\alpha$  was set at its minimum in this study, was reported from a reading taken at noon when the radiation and temperature are highest.

Peri *et al.* (2005) further showed that 4.0% nitrogen concentration was a critical value below which  $\alpha$  started to decrease at  $0.061 \mu\text{molCO}_2/\mu\text{mol photon irradiance per } 1.0\%$  nitrogen with chlorophyll content increasing with herbage nitrogen and ranged from  $0.05 \text{ gm}^{-2}$  at 1.5% nitrogen to  $0.96 \text{ gm}^{-2}$  above 5.5% nitrogen. They observed that at 4.0% nitrogen, when  $\alpha$  started to decrease, chlorophyll content was  $0.60 \text{ gm}^{-2}$ . The association indicated that the differences in the concentration of nitrogen compounds found in the chloroplasts were probably responsible for the changes in  $\alpha$  (Grindlay, 1997). Results differ amongst species. For instance, Hirose and Werger (1987) reported that  $\alpha$  decreased linearly with a decline in nitrogen concentration at  $0.0125 \mu\text{molCO}_2/\mu\text{mol photon irradiance per } 1.0\%$  nitrogen for *Solidago altissima*. Following the analysis presented above, combined with the information obtained from the literature, parameter values were selected to model cocksfoot and annual ryegrass pastures.

Following inclusion of a germination procedure in LincFarm, extra parameters are required to simulate seed germination and emergence for annual ryegrass and are presented in Table 4-3. Sections 4.3 and 4.4 present analysis of the suitability of the given parameter values to model cocksfoot and annual ryegrass respectively by comparing model output and data obtained from field experiment.

#### **4.3. Selected Set of Parameters to Model Cocksfoot Growth and Productivity**

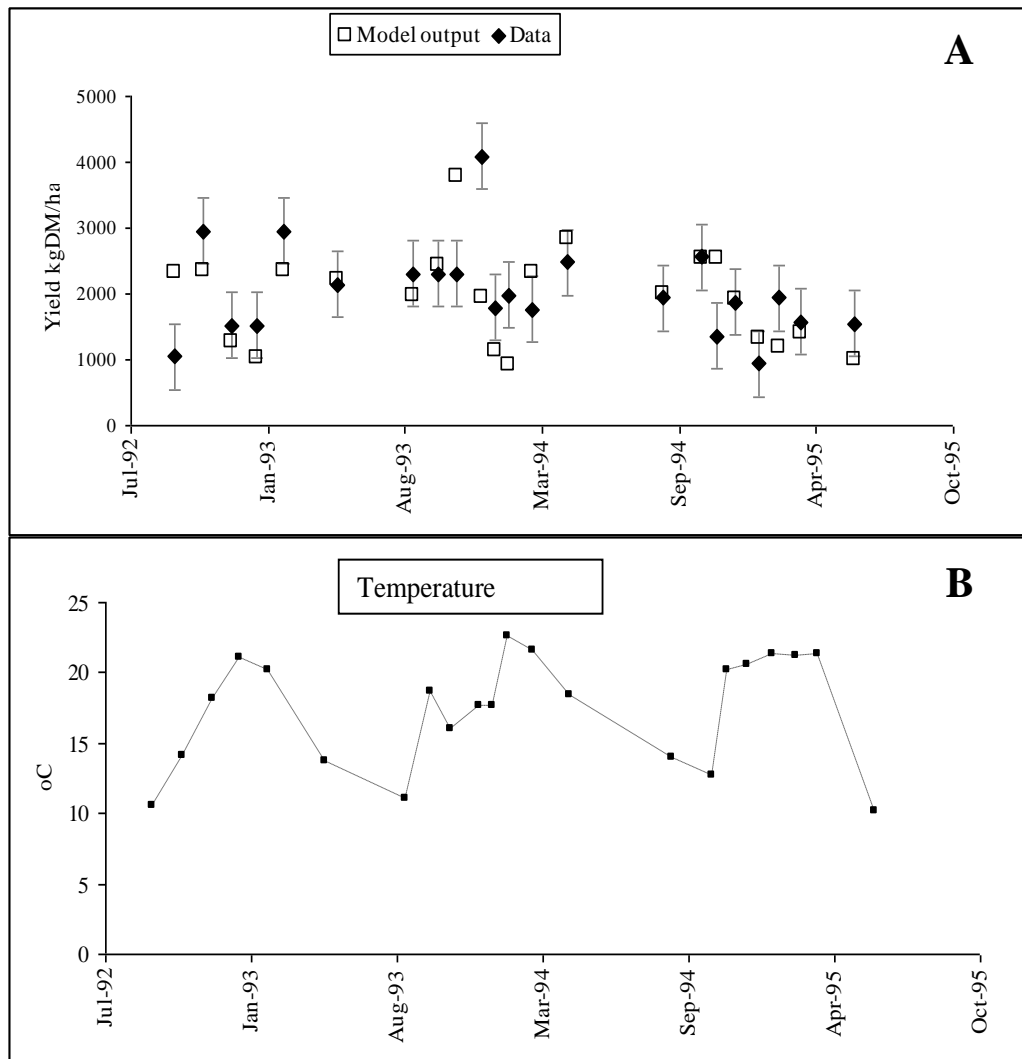
Figure 4-3 shows plots of model output and growth data obtained from field experiment for cocksfoot. The field data was obtained from the New Zealand Plant Breeding Association (NZPBA, 1999).



**Figure 4-3:** Plots of model output for cocksfoot growth rate compared to observed growth data obtained from field experiment for cocksfoot

Modelled pasture growth rates were within the field data values except for a the months of April and December where it fell below the data and in a period after August when it tended to overestimate growth rate, though marginally. Generally, the model prediction fell within one standard deviation. The model also tended to capture the growth pattern indicating that it is responsive to changes in seasons (representing variation in environmental variables within which the plant grows) which are represented by different months. For instance, pasture growth would be expected to decrease in the winter season (June, July and August in the Southern Hemisphere). This is captured well both by field data and the results from model predictions for cocksfoot.

Figure 4-4A shows comparison between simulated pasture yield and data from NZPBA (1999) over three years while Figure 4-4B shows a plot of the temperature profile for the period. By mapping Figure 4-4A on 4-4B shows that yield varied with temperature. Peri *et al.* (2005) gave a detailed description of pasture productivity in relation to varying temperature when moisture and nitrogen are non-limiting. Statistical evaluation of the performance of the model using methods described by Kobayashi and Us Salam (2006) is given in section 4.6 below.



**Figure 4-4:** A comparison between simulated cocksfoot yield and data (A) for different periods in different years in relation to temperature (B)

#### 4.4. Selected Set of Parameters to Model Annual Ryegrass

The LincFarm model did not incorporate a germination routine for annual pastures such as annual ryegrass. In the original model, these pastures were assumed to be sown as a crop and cut or harvested for feeding as stored feed rather than being grazed by the animals. This assumption though satisfactory, makes it time consuming if an experimental run covers a long period of time (this study simulation runs covered a period of 19 years) since sowing and cutting date(s) for all the years have to be defined in advance. This problem could be solved by incorporating a germination routine in the pasture growth model. A germination procedure was developed and incorporated in the LincFarm model. Temperature (germination and emergence thermal time requirements for annual ryegrass) and rainfall are required in seeds germination and subsequent emergence. Germination and emergence thermal time (Tt) requirements for annual ryegrass are 90 and 145 degree-days ( $^{\circ}\text{Cd}$ ) respectively (Moot *et al.*, 2000). A rainfall of between 10.0-13.0 mm after 1<sup>st</sup> of March (Cocks and Donald, 1973,

Gramshaw and Stern, 1977) has been noted to cause germination and subsequent emergence.

Germination is considered to occur when the shoot reaches 1.0 mm in length. Hill *et al.* (1985) obtained a dry weight per tiller and leaf after germination of 0.15 and 0.03 grams respectively, number of leaves per tiller to be 3.2 and the total number of tillers to be 25 at day 35 since sowing. This information together with a seed sowing rate of 18.0-25.0 kg ha<sup>-1</sup> (Agricom, 2010) and a 90.0% germination rate obtained from Hill *et al.* (1985) was used to estimate the annual ryegrass initial dry matter per hectare. Each kilogram of the annual ryegrass seed contains 100,000 seeds (Hill *et al.*, 1985). A total of 22.14 kg DM ha<sup>-1</sup> initial annual ryegrass mass was obtained for New Zealand Canterbury dryland sheep systems growing conditions.

The LincFarm model requires parameters for different sub-models to be declared in different input files. Table 4-3 shows the extra parameters needed to run LincFarm with the addition of the germination routine.

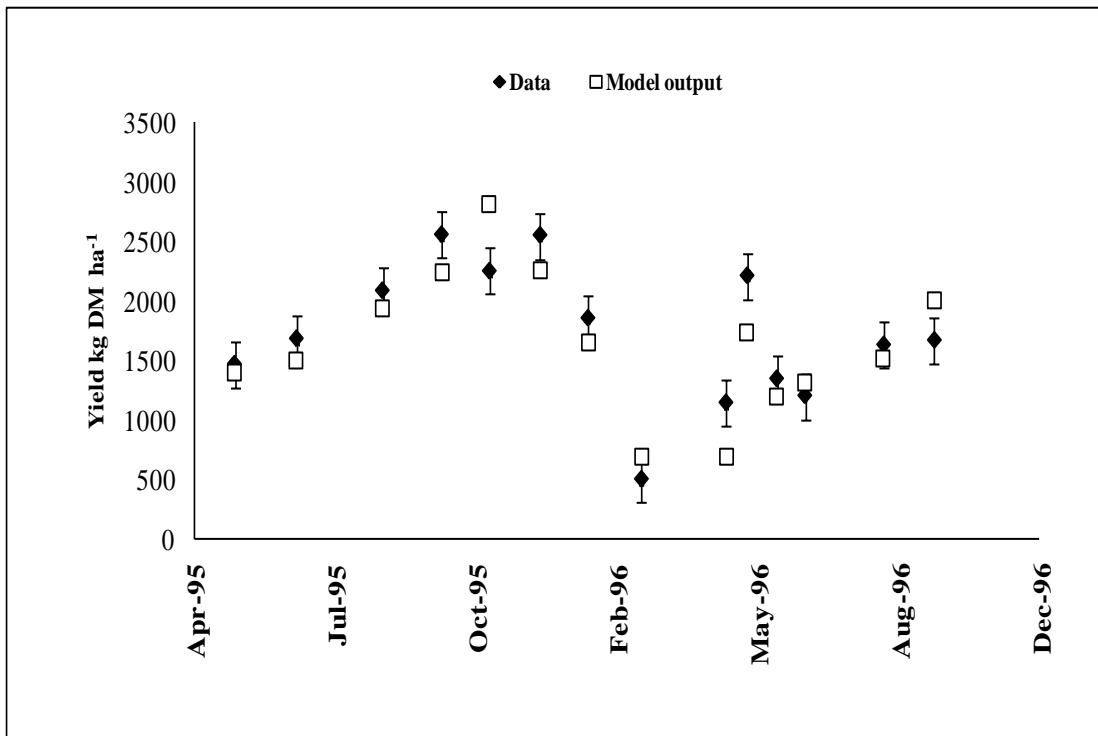
**Table 4.3:** Germination sub-model parameters

Parameter number	Parameter	Description	Units	Value
<b>Germination parameters</b>				
1	Pl_type <sup>1</sup>	plant type	-	0.0
2	Sow_date	sowing date	day	60
3	T_base <sup>2</sup>	base temperature	degree-days	1.5
5	R_heat	heat requirement for germination and emergence	"	81.5
6	R_rain	rain requirement for germination and emergence	mm	10.0
7	Init_DM	initial dry matter	Kg DM ha <sup>-1</sup>	22.140
11	F_date	flowering date	day	314
12	K_days	killing days	days	14

<sup>1</sup>A value of 0 is given for annual pastures

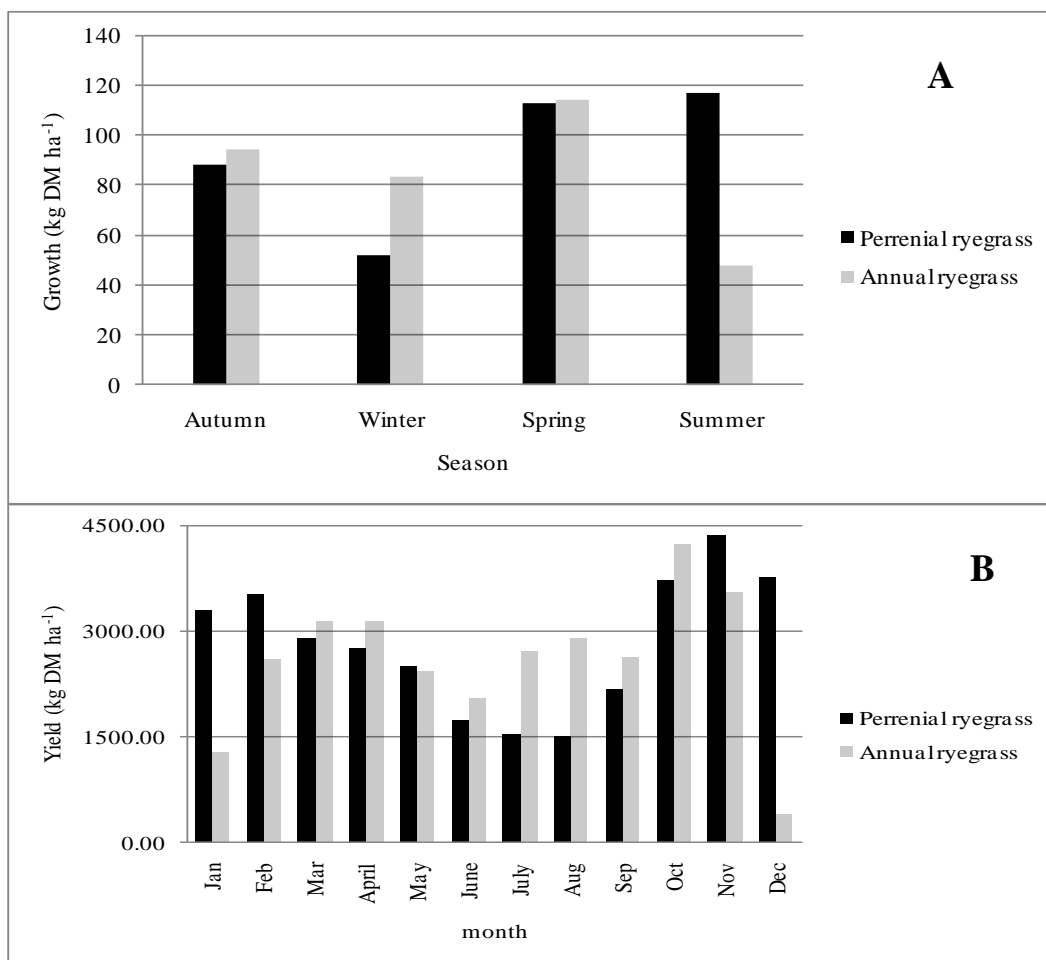
<sup>2</sup>Used in estimating thermal time requirements for germination and emergence

Since the pasture sub-model was tested for its responsiveness in relation to environmental condition (see Figure 4-4B for temperature) only results for model output and data are presented for annual ryegrass. Figure 4-5 shows plots of model output for annual grass yield over a period of three years compared to measured growth data obtained from NZPBA (1999). Figure 4-5 shows that there is no need to vary the parameters from their original values given in the literature as the model output values closely matches the field data values except for some few data points around October of the year 1995 which fell outside the error margins though not with so great margins as to warrant reconsidering the values of some of the parameters. Furthermore, error values around the same time in the year 1996 were smaller. Again, statistical evaluation of the model is discussed in section 4.6.



**Figure 4-5:** A comparison between simulated annual ryegrass yield and data for different periods in different years

Perennial and annual ryegrass exhibit differences in their growth mainly due to their response to environmental variables (pers. Com, A.C.Bywater, Lincoln University) with annuals accumulating more mass than the perennials under cooler temperatures. Figure 4-6 compares annual and perennial ryegrass growth for different months (A) and yield for different seasons (B). It is evident that the model is able to capture the growth differences between the perennial and annual ryegrass under similar temperature regime. As the temperatures start to decrease progressively, annual ryegrass growth gradually surpasses perennial ryegrass especially towards the start of winter explaining the small observable difference between the two pastures in autumn. The difference increases in the winter season with annual ryegrass showing greater growth potential under low temperatures. The perennial ryegrass conversely performs better than the annual ryegrass under hot summer weather. This emphasizes the reason for considering the different pasture types in the climatic variability management policies under test in this study.



**Figure 4-6:** A comparison between simulated annual and perennial ryegrass pastures growth for different seasons (A) and yield for different months (B)

Unlike the perennial ryegrass, the annual ryegrass is deemed to die approximately 14 days after flowering (pers. com, G.R. Edwards, Lincoln University) and that explains its sharp decline in late November following flowering (taken to occur on day 314 of the year; 10<sup>th</sup> November in this study).

#### 4.5. Choice of Parameter Set for Simulating Lucerne Growth and Productivity

The process of selecting parameter estimates capable of simulating lucerne growth and productivity followed that of the annual ryegrass and cocksfoot. Though the pasture types differ in that lucerne is a legume pasture, a perturbation analysis of the model parameters showed a similar pattern in the error sum of squares (ESS; see equation 4:1) for TDM, GDM, LM and the summed ESS. In addition to the parameters presented in Table 4-1, the lucerne utilises a root model which requires an extra 9 parameters to be defined. The root model is important in modelling lucerne growth and productivity in situations where photosynthesis exceeds the requirements for carbon, as the excess carbohydrates are stored in its perennial organs (taproots and crowns) mainly in the form of starch (McAdam and Nelson, 2003).

Table 4-4 shows a list of all the parameters required to simulate lucerne growth and

productivity. Since grass pasture does not use the root model, a perturbation analysis was carried out for the root model parameters and they were shown not to significantly vary the TDM, GDM and LM components with the exception of a parameter describing recycled DM (*rc\_alpha*). A value of 0.0017 kg DM ha<sup>-1</sup> for *rc\_alpha* found in the literature was used in this study as it resulted in acceptable growth and productivity for all scenarios tested.

The lack of significant changes in TDM, GDM and LM components after varying the other parameters was expected given the observation by Peri *et al.* (2005) and D.J. Moot (pers com) noted earlier, that the differences in parameters controlling response to the main environmental variables rather than the parameters describing the pasture species in plant growth models influence net leaf photosynthesis and subsequently productivity. For many plant species in ambient [CO<sub>2</sub>] conditions, the main determinants of growth are temperature, water (Radcliffe and Baars, 1987; Moloney, 1991; Barker *et al.*, 1993) and nitrogen status (Donohue *et al.*, 1981; Moloney *et al.*, 1993; Peri *et al.*, 2001). Following these observations and based on previous experience in obtaining and setting parameter values for annual ryegrass and cocksfoot grass pastures, values obtained from the literature search were used initially to simulate lucerne growth and productivity in this study and are presented in Table 4-4. Where values were not available for lucerne specifically, those from related pasture species (at least in growth characteristics) were considered. As discussed below and in section 4.6, these appear to provide an adequate representation of lucerne growth for the present purpose.

**Table 4.4:** Parameter estimates for simulating lucerne growth and productivity

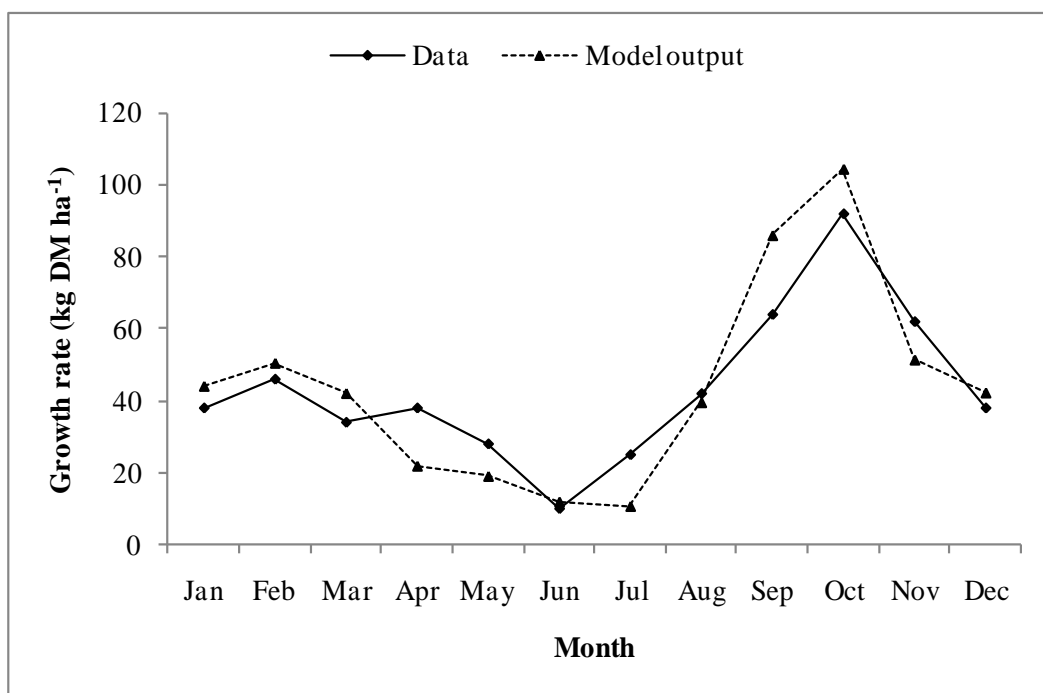
Parameter number	Parameter	Description <sup>1</sup>	Value	Units	Sources
<b>Growth model parameters</b>					
1	GV[gv_Y]	efficiency of converting substrate to structure	0.75	mg[CO <sub>2</sub> ](kg DM ha <sup>-1</sup> ) <sup>-1</sup>	Woodward <i>et al.</i> (1998)
2	GV[gv_pieV]	assimilate partition to vegetative growth	0.88	mg[CO <sub>2</sub> ]m <sup>-2</sup>	Duru and Langlet (1995)
3	GV[gv_pieR]	assimilate partition to reproductive leaf	0.88	"	"
4	GV[gv_pieS]	assimilate partition to reproductive stem	0.27	"	Cunningham and Volenec (1998).
5	GV[gv_pieL]	assimilate partition to root	0.60	"	Brown (2004)
6	GV[gv_gamma]	conversion from kgDMha <sup>-1</sup> to mg[CO <sub>2</sub> ]m <sup>-2</sup> mass	161	mg[CO <sub>2</sub> ](kg DM ha <sup>-1</sup> ) <sup>-1</sup>	Woodward <i>et al.</i> (1998)
7	GV[gv_R]	target mass	2.0		Teixeira (2006)
8	GV[gv_deltaE]	worm removal constant	0.0005		Woodward (1997)
9	GV[gv_deltaD]	base decomposition rate	0.0148	kg ha <sup>-1</sup> d <sup>-1</sup>	Andrew (2009)
10	GV[gv_sigma]	leaf senescence rate	0.0011	kg ha <sup>-1</sup> d <sup>-1</sup>	Woodward <i>et al.</i> (1998)
11	GV[gv_R <sub>m1</sub> ]	dark respiration	4.32	mg[CO <sub>2</sub> ]g <sup>-1</sup> h <sup>-1</sup>	Teixeira (2006)
12	GV[gv_R <sub>m2</sub> ]	leaf respiration	0.078	mg[CO <sub>2</sub> ]g <sup>-1</sup> h <sup>-1</sup>	Andrew (2009)
13	GV[gv_stress1]	water stress lower limit	-3.8	Mpa	Whitfield <i>et al.</i> (1986)
14	GV[gv_stress2]	water stress upper limit	-0.2	Mpa	"
<b>Photosynthesis model parameter</b>					
15	Q	maximum photosynthesis at reference temperature	2.0	mg[CO <sub>2</sub> ]m <sup>-2</sup> (leaf)s <sup>-1</sup>	Woodward (1997)
16	T <sub>ref</sub>	optimal temperature	20.0	°C	Atkin <i>et al.</i> (2000)
17	T <sub>0</sub>	half optimal temperature	40.0	°C	Fick <i>et al.</i> (1988)
18	Alpha	peak leaf photosynthesis efficiency	0.022	mg[CO <sub>2</sub> ]J <sup>-1</sup>	Teixeira (2006)
19	Theta	curvature parameter in leaf photosynthesis response	0.61	dimensionless	"
<b>Reproduction model parameter</b>					
20	A	minimum sustainable SLA	0.092	m <sup>-2</sup> (leaf) m <sup>2</sup> (ground)	Gosse <i>et al.</i> (1984)
21	B	difference between A and SLA when grown in the dark	-0.0017	"	"
22	C	instantaneous rate of change of SLA	0.0	"	"
23	M	rate of stem maturation	0.0	mg[CO <sub>2</sub> ]m <sup>-2</sup> (ground) d <sup>-1</sup>	Teixeira (2006)
24	Flg	flag leaf fraction of the total reproductive leaf	0.0		"
25	t1	day when stem elongation starts	320	day	Hare (1986)
26	t2	day when stem maturation starts–ear emergence	90	day	"
27	t3	day when stem senescence starts	90	day	"

Parameter number	Parameter	Description <sup>1</sup>	Value	Units	Sources
28	t4	day when stem elongation ceases	75	day	"
29	k	extinction coefficient	1.03	m <sup>-2</sup> (ground) m <sup>2</sup> (leaf)	van Henten and van Straten (1994)
30	kv	extinction coefficient vegetative leaf	0.94	"	Gosse <i>et al.</i> (1982)
31	kr	extinction coefficient reproductive leaf	0.94	"	"
32	km	extinction coefficient reproductive stem	0.94	"	"
33	epsilon	reproductive leaf elevation	0.0008	kg DM ha <sup>-1</sup>	Woodward (1997)
34	c <sub>m</sub>	light capture efficiency of mature stem	0.003	ha kg DM <sup>-1</sup>	Thornley and Johnson (2000)
35	c <sub>d</sub>	light capture efficiency of leaf, sheath and dead material	0.009	"	"
36	c <sub>mr</sub>	light capture efficiency of reproductive stem and leaf	0.00036	"	"
37	w <sub>d</sub>	proportion of dead material in mixed layer	0.28	kg DM ha <sup>-1</sup>	Thornley and Johnson (2000)
<b>Specific leaf area</b>					
38	minSLA	leaf area ratio of vegetative green	0.0019	ha (leaf) kgDM <sup>-1</sup>	Woodward (1997)
39	invCoff	inverse coefficient (SLAc)	0.60		Peacock (1975)
40	sigA	leaf lifespan (SigA)	0.0003	day	Woodward <i>et al.</i> (1997)
41	sigB	leaf lifespan (SigB)	0.0074	day	Lemaire and Agnusdei(2000)
<b>Assimilate model parameters</b>					
42	Cubic	current day of the year	180	day	
43	Quad	reference day	30	"	
44	Linear	Percent	1.0	percent	
45	Const	Percent	1.0	"	
46	qr	Structural/storage mass ratio	0.465	ratio	Kendall <i>et al.</i> (1994)
<b>Root model parameters</b>					
47	qt	Q tops	0.47	mg[CO <sub>2</sub> ]m <sup>-2</sup> (leaf)s <sup>-1</sup>	"
48	rt_resp	root respiration	0.015	mg[CO <sub>2</sub> ]g <sup>-1</sup> h <sup>-1</sup>	Smith <i>et al.</i> (1950)
49	st_alpha	recycled DM	0.1315	kg DM ha <sup>-1</sup>	Li <i>et al.</i> (1996)
50	st_gamma	recycled DM	895	"	Bowley <i>et al.</i> (1998)
51	rc_alpha	recycled DM	1.7	"	Bowley <i>et al.</i> (1999)
52	rc_gamma	recycled DM	0.0	"	<i>estimated</i>
53	rc_d1	recycled DM–day lower limit	35	day	Teixeira (2006)
54	rc_d2	recycled DM–day upper limit	212	"	"
55	rm_pie	used in apportioning while vegetative	2.0		"

<sup>1</sup>See Table 4-1 for the equation in which the parameter appears

Figure 4-7 shows plots of model output and growth data obtained from field

experiments for lucerne. The field data was obtained from Smetham (1970) in studying growth rates of pure legumes grown at Lincoln, New Zealand in the production season 1970-71.



**Figure 4-7:** Plots of model output for lucerne growth rate compared to observed growth data obtained from field experiment

Generally, the modelled pasture growth rates were within one standard deviation of the field data with an exception for the periods around April and July where model output tended to fall below the field data and in a period around September when it tended to overestimate the growth rate. In almost all instances, the model prediction fell within one standard deviation from the mean. This indicates that the model parameters obtained from literature search are sufficient to simulate lucerne growth and productivity in this study.

#### 4.6. Pasture Growth Model Performance Evaluation

The model performance was tested following methods discussed by Kobayashi and Us Salam (2000) discussed in detail in section 2.9. Data from New Zealand National Forage Variety trials obtained from NZPBA (1999) was used in testing the model performance. In all, a total of 6 data-sets for each pasture type were available and came from productivity trials of different annual ryegrass and cocksfoot cultivars grown in New Zealand. Each set was a small plot cutting trial using pure swards, with/without grazing, with each cultivar replicated 4 times and run for 3 years.

Table 4-5 presents a summary of the pasture model evaluation with respect to its suitability in simulating Cocksfoot, Annual ryegrass and lucerne growth. MSD indicates the

overall deviation of the model output from the measurement while its components discussed in Section 2.9 represent different aspects of the deviation.

**Table 4.5:** Statistics for the set of pasture model parameters<sup>1</sup> used in simulating yield of cocksfoot, annual ryegrass and lucerne (kg ha<sup>-1</sup>)

Criterion <sup>2</sup>	Data		
	Cocksfoot	Annual ryegrass	lucerne
MSD	16.43	43.67	20.17
RMSD	4.05	6.53	5.03
SB	2.21	11.89	3.14
SDSD	1.17	3.24	1.68
LCS	13.04	32.45	16.29
r	0.97	0.95	0.96

<sup>1</sup>See Tables 4-1 and 4-4 for the parameters

<sup>2</sup>See Section 2.9 for description of the evaluation criteria

In all cases, LCS which relates to the pattern of fluctuations across the measurements is the major component contributing to MSD. For instance, it contributed 79.37% of the MSD while SB, which measures the difference between the means of the predicted and observed values, only contributed 13.45% for cocksfoot. Such big LCS mean the model failed to simulate the pattern of the fluctuation across the  $n$  measurements. However, in this case the values are big relative to MSD which is itself small. The SDSD, which reflects the ability to simulate the magnitude of fluctuations among the observations, is very small in all cases. In all three cases, the high values given by the correlation coefficient indicate that small differences exist between model output and measurements using the current set of parameters described above.

#### 4.7. Choice and Incorporation of Simple Crop Sub-model in LincFarm Model

Forage crops are grown widely throughout New Zealand to supplement pasture in times of scarcity in the dairy, sheep and beef sectors (de Ruiter *et al.* 2009). In addition to the grass pastures described so far, forage crops were included in this study and supplied feed to the animals during the winter and late summer seasons. This section describes the choice of a simple crop DM accumulation sub-model and its subsequent inclusion in the LincFarm model.

The original LincFarm model did not explicitly include a crop model but instead utilised the mechanistic pasture growth sub-model to simulate the growth of crops. This required that an initial amount of leaf, stem and root (for crops with root reserve and capable of re-growth after grazing) be defined on the day the crop was presumed sown. The sow crop event (see illustration 3 in section 3.4.2.1) then took up the information and grew the defined crop from the date the event was encountered during the simulation. Parameter estimates required by the mechanistic pasture growth sub-model utilised by LincFarm (presented in

Table 4-1) are not readily available for forage crops such as Brassicas. Therefore, it was decided to develop a simpler forage crop sub-model using the information available that would be used to simulate forage crop DM accumulation in farm simulations where these crops are used to supply animal feed.

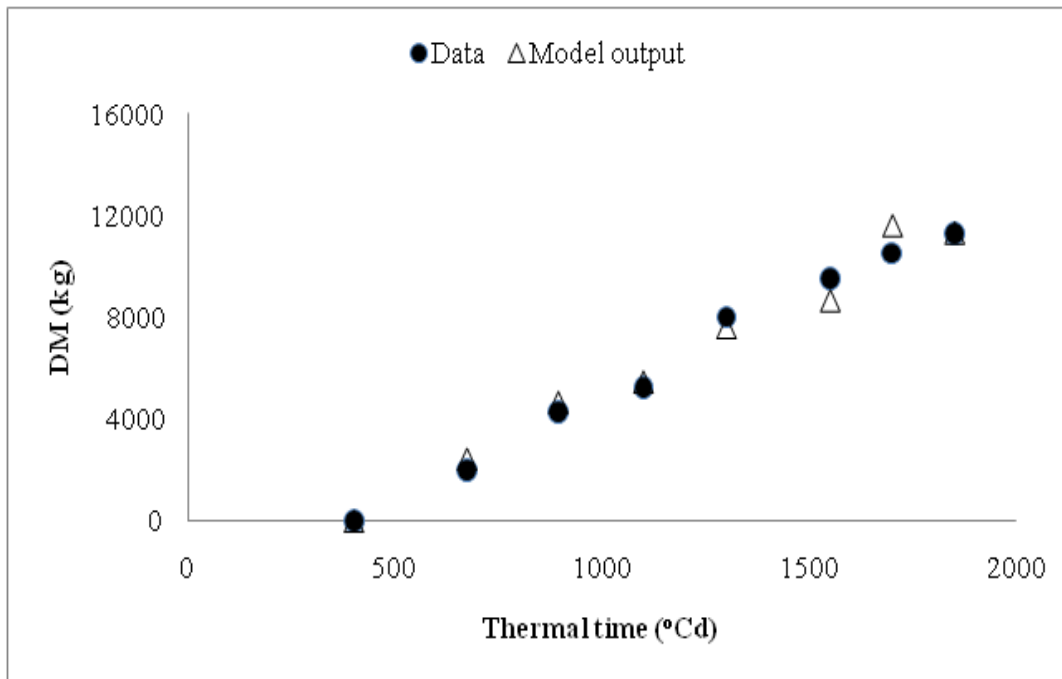
Numerous models have been proposed to describe the phenological development of plants as a function of environmental variables in an effort to overcome the inadequacies of calendar days in projecting crop development (Morrison *et al.*, 1989). One such model is thermal time (Tt), also known as heat units or growing degree days. The model uses the accumulated heat available to predict crop growth (Morrison *et al.*, 1989; Mackenzie *et al.*, 1999). Though thermal time is not a direct driver of plant growth (Adams, 2004), it influences the rate of leaf appearance and expansion (Collie and McKenzie, 1998) which subsequently affect light interception (the main driver of growth) and photosynthetic rate. The Tt concept is important in terms of establishment and leaf appearance and subsequently the energy capture and DM production.

#### 4.7.1. Kale DM Accumulation Using Tt Model

Various studies have established a linear relationship between number of leaves per stem and accumulated temperature ( $^{\circ}\text{Cd}$ ) in wheat (Gallagher, 1979), corn (*Zea mays* L.) (Warrington and Kanemasu, 1983), summer rape (Morrison and McVetty, 1991), Pasja (*Brassica campestris x napus*) (Nanda *et al.*, 1995), and kale (Wilson *et al.*, 2004). Adams *et al.* (2005) observed that the yield of brassicas (four cultivars: Goliath rape, Green Globe turnip, Gruner kale and Kestrel kale) was linear in relation to thermal time. Chakwizira (2008) identified a strong linear relationship ( $R^2=0.99$ ) between DM accumulation and Tt for kale with and without fertiliser application while studying the growth and development of ‘Pasja’ and kale crops. The DM accumulation for kale was  $800.0 \text{ kg DM ha}^{-1}$  for every  $100.0 \text{ }^{\circ}\text{Cd}$  ( $8.00 \text{ kg DM}$  for every  $^{\circ}\text{Cd}$ ) for the mean of all P fertiliser treatment (Chakwizira, 2008) at base temperature of  $0.0 \text{ }^{\circ}\text{C}$  (Moot *et al.* 2007). Though other production factors such as soil fertility, pest and diseases affect forage crop DM accumulation, most often the main DM-yield-limiting factor is soil water (Wilson *et al.*, 2006). Hence soil moisture has been included as a modifier in the equation for estimating the kale DM accumulation:

$$\text{DM} = 8.00 \times \text{MoistureMd} \times \text{Tt} \quad (4:2)$$

where MoistureMd represents the ratio between actual evapo-transpiration and potential evapo-transpiration. Figure 4-8 shows the results for kale DM accumulation from this simple model compared with data obtained from Chakwizira (2008).



**Figure 4-8:** Observed and model predicted values for kale DM accumulation

The plots indicate that the simple model resulted in acceptable values for kale DM and satisfies the expected requirements in simulating kale DM accumulation in this study.

#### 4.7.2. Leaf Turnip DM Accumulation

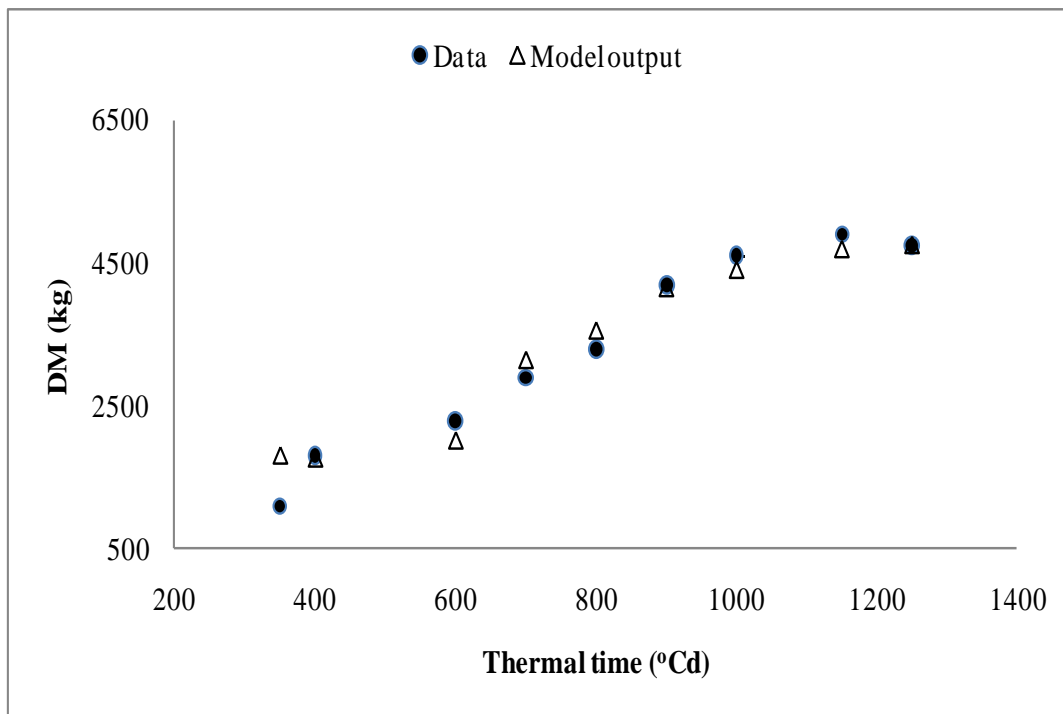
According to the study by Chakwizira (2008), DM yield of P fertilised leaf turnip Pasja was 420.0 kg DM ha<sup>-1</sup> for every 100.0 °Cd (4.20 kg DM for every °Cd) considering a base temperature of 0.0 °C. Using the same simple crop model, DM accumulation is estimated as:

$$DM = 4.20 \times \text{MoistureMd} \times Tt \quad (4:3)$$

Pasja differs from kale, in that it has a crown from where leaves grow enabling leaf regeneration after defoliation. The crown is usually at or below ground level. A study by Chakwizira (2008) established that the high leaf to stem ratio obtained for Pasja indicated that its DM was essentially made up of the leaf with the crown constituting less than 6.0% of DM (48.0 g/m<sup>2</sup>) which closely reflects the value of approximately 8.0% reported by Wilson *et al.* (2006) at Lincoln, New Zealand.

Figure 4-9 shows the results for Pasja DM accumulation from the simple model compared with data obtained from Chakwizira (2008). The DM accumulation for Pasja does not start at zero since growth occurs from the crown. This is achieved by setting the expected DM for the crown (stem) and leaf in the sow crop event during initialisation of Pasja crop in the model farm.

The input variables for the simple crop model also allow a user to define the minimum pasture cover (in percent) below which no crop re-growth occurs following grazing. Setting the value to zero means a crop that has been grazed down and has a potential to re-grow, as is the case with Pasja does not die.



**Figure 4-9:** Observed and model predicted values for Pasja DM accumulation

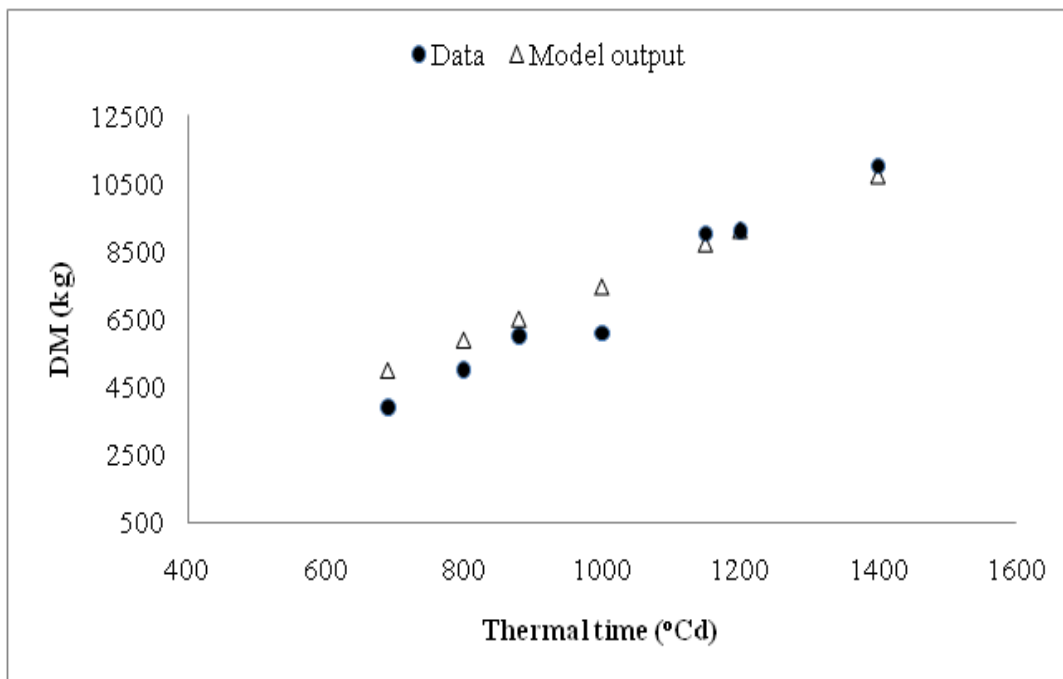
The Pasja DM values obtained from running the simple crop model compared well with data obtained by Chakwizira (2008) as shown in Figure 4-9. The total amount of Pasja DM obtained from running the sub-model compared with the observed DM accumulation for the period simulated differed by 1.59% margin. These results show that the simple crop model is capable of describing DM accumulation for Pasja within acceptable margins.

#### 4.7.3. Rape DM Accumulation

The simple crop model was fitted with parameters considered as appropriately describing rape DM accumulation. A base temperature of 4.0 °C obtained from Adams *et al.* (2005) was used. The value from Adams *et al.* represented an average base temperature for kale, rape and turnips in a study designed to describe the effect of forage sowing time on yield in different areas of New Zealand and to provide parameters useful in the development of a model of brassica growth. Morrison *et al.* (1989) found a base temperature for leaf appearance of “Westar” summer rape (*Brassica napus* L.) of 5.0 °C.

A value of 6.67 kg DM ha<sup>-1</sup> per °Cd obtained from Adams *et al.* (2005) was used in describing growth rate of rape in the simple crop model. Results for field data (Adams *et al.*

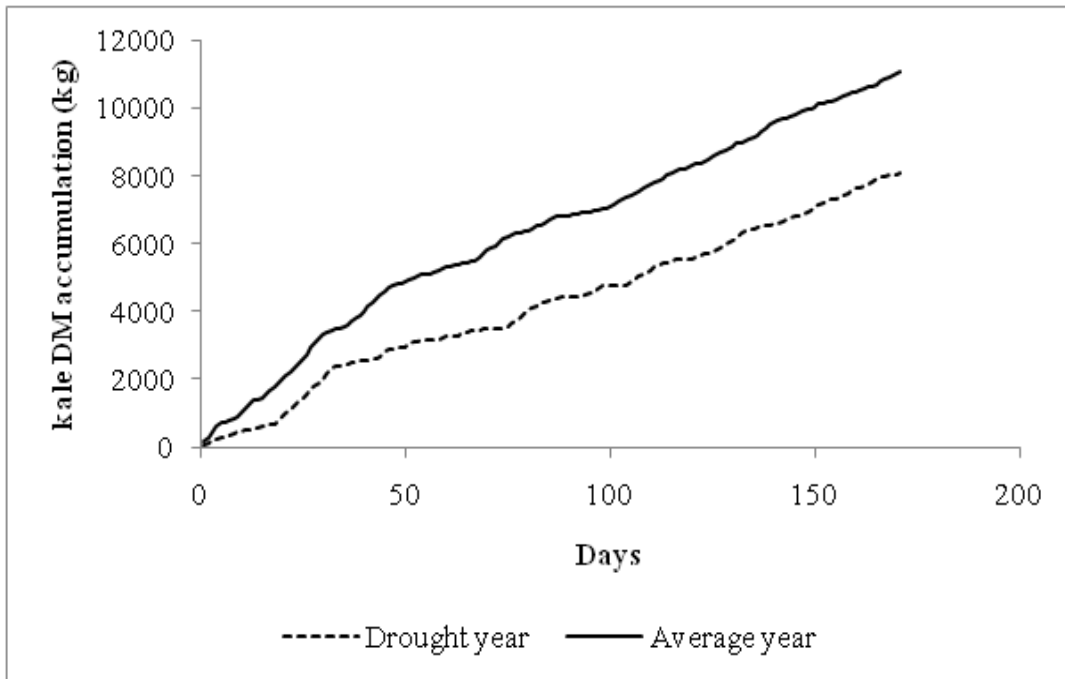
2005) and model output presented in Figure 4-10 show that the simple crop model was able to acceptably describe rape DM accumulation.



**Figure 4-10:** Observed and model predicted values for rape DM accumulation

The standalone crop DM accumulation sub-model was incorporated in the LincFarm grazing sheep model, following which various tests were carried out to ensure that the revised model performed as expected. The tests involved comparing the extended model output with those of the stand alone crop DM accumulation sub-model. The output of the incorporated crop DM sub-model and the standalone sub-model were found to be equal. Consequently, the incorporated crop DM accumulation sub-model was considered to be suitable for simulating DM accumulation for brassica crops.

Figure 4-11 shows kale DM accumulation in a season receiving an average amount of rainfall (average year) and one experiencing a less than average rainfall here referred to as a drought year (1988-89 production season in Canterbury New Zealand). The pattern for DM accumulation was similar for Pasja and rape for the two years and therefore only the kale plot is presented. As expected, the amount of kale DM accumulation is significantly less in the drought year.



**Figure 4-11:** Kale DM accumulation in a season receiving an average amount of rainfall (average year) and one experiencing a less than average rainfall

It is important to ensure that crops respond to different management events defined in LincFarm such as sow, cut, and feed hay. The cut hay event harvests the crop and places it in the hay barn from which it is subsequently fed to the animals. The hay feeding event applies to any feed (including crop sown) which has been defined in the base definition file (FarmSim.BDF). In all cases, the sown crop responded to the relevant management events as required and thus the sub-model was considered to be suitably incorporated in the LincFarm model.

## CHAPTER 5

### Beef Growth and Composition Sub-model

#### 5.0. Introduction

Some management strategies tested in this study involve systems that include growing beef cattle as a flexibility option. This chapter describes the procedure and test used in choosing a suitable beef growth and composition model. The beef model used is the Davis growth model (Oltjen *et al.*, 1986a) and the main activity required is parameter estimation to establish a set of parameters that correctly simulate growth and composition of young growing cattle in New Zealand grazing conditions. The chosen beef growth and composition sub-model with the new set of parameters was incorporated in LincFarm model which was originally designed to simulate a grazing sheep farm and sheep were the only livestock included.

#### 5.1. Model Description

Equations for DNA accretion and protein synthesis used by Oltjen *et al.* (1986a) in the beef growth and composition model are given by:

$$\frac{dDNA}{dt} = k_1 \times \text{PROT}_t^{E_1} \times (\text{DNA}_{MX} - \text{DNA}) \times \text{NUT}_1 t \quad (5:1)$$

$$\frac{d\text{PROT}}{dt} = \text{SYN} - \text{DEG} \quad (5:2)$$

$$\text{SYN} = k_2 \times \text{PROT}_t^{E_2} \left( \frac{\text{PROT}_{MX}}{\text{DNA}_{MX}} - \frac{\text{PROT}_t}{\text{DNA}_t} \right) \times \text{NUT}_2 t \quad (5:3)$$

$$\text{DEG} = k_3 \times \text{PROT}_t^{E_3} \times \text{NUT}_3 t \quad (5:4)$$

where PROT (kg) is empty-body protein,  $t$  (days) is age, MX signifies maturity,  $\text{NUT}_1$ ,  $\text{NUT}_2$  and  $\text{NUT}_3$  are dimensionless nutritional terms, SYN ( $\text{kg day}^{-1}$ ) is synthesis, DEG ( $\text{kg/day}$ ) is degradation,  $k_1$ ,  $k_2$  and  $k_3$  are rate constants of synthesis and degradation,  $E_1$ ,  $E_2$  and  $E_3$  are exponents of tissue mass.

The Oltjen *et al.* (1986a) model was originally parameterised using individual data from Garrett (1980) and Byers and Moffitt (1979) for medium-framed British steers. Utilising data from Brazilian Nellore cattle, Sainz *et al.* (2006) found that the original model under-predicted final empty body mass, body fat and energy and that it was necessary to use revised

model parameters to account for a higher efficiency of energy utilisation in the Nellore animals. This observation emphasises the potential importance of estimating breed-specific parameters in the Oltjen *et al.* (1986a) model when applying it to a different production systems. For example, when modelling growth and composition of New Zealand grazing beef cattle it may be necessary to re-estimate model parameters to account for differences in composition and rates of growth, as influenced by breed, frame size and feed type.

When testing their model, Oltjen *et al.* (1986a) showed that the model was sensitive to protein and DNA exponents ( $E_1$ ,  $E_2$  and  $E_3$ ). However, no improvement was observed when nutrition (NUT) was decreased. Further, the model was shown to be relatively sensitive to maximum DNA ( $DNA_{MX}$ ). Unrealistically low  $DNA_{MX}$  estimates prohibited the model equation from best representing DNA accretion. The rate of DNA synthesis is relatively fast in early life for smaller animals. Breed effects have also been shown to influence DNA synthesis (Taylor, 1980). Taylor (1980) developed the DNA synthesis-breed concept for inter-specific comparisons, relating mature body weight to standardized age and rate variables while St Pierre and Bywater (1987) developed a means of adjusting for mature body size.

The Oltjen *et al.* (1986a) model described above has been developed further to represent body protein in two pools: visceral and non-visceral (muscle) (Oltjen *et al.*, 2006). In the revised model, maximum attainable muscle is considered to be genetically fixed although the possibility of reaching the maximum depends on both the current intake and nutritional history of the animal (Sainz *et al.*, 1995). Net energy intake above maintenance ( $NE_g$ ) is used for muscle and visceral gain before its use for fat accretion (Oltjen *et al.*, 2006). This led to a simplification of previous equations (Oltjen *et al.*, 1986a) for viscera growth, also allowing gain of muscle or viscera at zero retained energy. The Oltjen *et al.* (2006) model predicted sheep empty body weight gain and fat content more accurately than the current Australian feeding systems.

In predicting composition of gain, growth is separated into three pools: visceral ( $v$ ) and non-visceral ( $m$ ) protein mass and empty body fat ( $f$ ). The following equations represent the revised model of Oltjen *et al.* (2006) expressed in terms of kilo joules (kJ):

$$\frac{dm}{dt} = P_m \left( NE_g + C_m + F_a \left( 1 - \frac{m}{m^*} \right) \right) \quad (5:6)$$

$$\frac{dv}{dt} = P_v \left( v^* - v \right) \quad (5:7)$$

$$\frac{df}{dt} = NE_g - \frac{dm}{dt} - \frac{dv}{dt} \quad (5:8)$$

where:

$$v^* = CS_1 \times MEI \times CS_2 \times m \quad (5:9)$$

and:

$$F_a = \left(1 - \frac{m}{m^*}\right)^{e_2} \quad (5:10)$$

with these equations, if energy intake is near maintenance, body protein can be gained and fat lost in the immature animal.  $p_m$ ,  $p_v$ ,  $c_m$ ,  $CS_1$ ,  $CS_2$  and  $e_2$  are constants. MEI is metabolisable energy intake. Note that  $p_m$  and  $p_v$  separate the  $NE_g$  into  $m$  and  $v$ .

$$NE_g = MEI - HP \quad (5:11)$$

where HP (kJ) is the total heat production set to respond to changes in muscle and visceral growth and is of the form:

$$HP = b_1 m \times b_2 v + b_3 \frac{dm}{dt} + b_4 \frac{dv}{dt} \quad (5:12)$$

thus:

$$HP_{maint} = b_1 m \times b_2 v \quad (5:13)$$

where  $b_{1-4}$  are regression coefficients for observed and predicted muscle, viscera, and muscle and viscera daily gain and  $HP_{maint}$  is the heat production for maintenance.  $NE_g$  is used for viscera and muscle tissue gain before its use for fat accretion (Oltjen *et al.*, 1986b). The empty body weight (EBW) of the animal is obtained by integrating the relationship:

$$\frac{dEBW}{dt} = \left[ \frac{\frac{dm}{dt} + \frac{dv}{dt}}{E_{prot} \times 0.2201} \right] + \left[ \frac{\frac{df}{dt}}{E_{fat}} \right] \quad (5:14)$$

where 0.2201 is the protein content of the fat-free EB,  $E_{prot}$  (23800) and  $E_{fat}$  (39600) are the energy densities of protein and fat respectively.

Analysis of model performance was carried out following methods discussed by Kobayashi and Us Salam (2000) which are described in detail in section 2.9.

## 5.2. Test Simulation One

The model was tested by simulating the experiment of Kitessa (1997). In that study, two experiments were carried out to investigate the influence of co-grazing sheep and cattle

on cattle liveweight (LW) and liveweight gain (LWG) under continuous or rotational stocking. In both experiments 9 yearling heifers were used with an additional 9 heifers in experiment two grazed alone on continuous or rotational stocking. Results for LW and intakes of Kitessa (1997) experiment I and II were used for model parameter estimation and evaluation respectively. Measurements were made of the initial and final LW, and the average daily intake. Data for the weights for  $m$ ,  $v$ , and  $f$  for each animal was not measured. Subsequently, various tests based on previous research were done to ensure the model predicted growth and apportioned  $NE_g$  amongst  $m$ ,  $v$  and  $f$  correctly. Firstly, model results were compared with results obtained for carcass protein to fat ratio carried out by Greathead *et al.* (2006), and with results by Garrett and Hinman (1969) who established the percentage protein in fat-free body mass. Garrett and Hinman (1969) considered EBW as the sum of fat and fat-free body mass with protein forming 22.01% of the mass.

The system of non-linear differential equations (equations 5:6, 5:7 and 5:8) describe three time dependent functions for  $m$ ,  $v$ , and  $f$ . These equations are integrated numerically over time to obtain  $m$ ,  $v$  and  $f$  as time-series values over the simulation time period. The initial conditions were calculated using the initial liveweight ( $LW_0$ ) following Soboleva *et al.*'s (1999) observations as:

$$m_0 = 0.078LW_0 \times E_{prot} \quad (5:15)$$

$$v_0 = 0.06LW_0 \times E_{prot} \quad (5:16)$$

$$f_0 = 0.13LW_0 \times E_{fat} \quad (5:17)$$

The  $v$  component was assumed to be 16.58% of the sum of the liver, heart, kidney, spleen and gastrointestinal tract weight (Oltjen *et al.*, 2001).

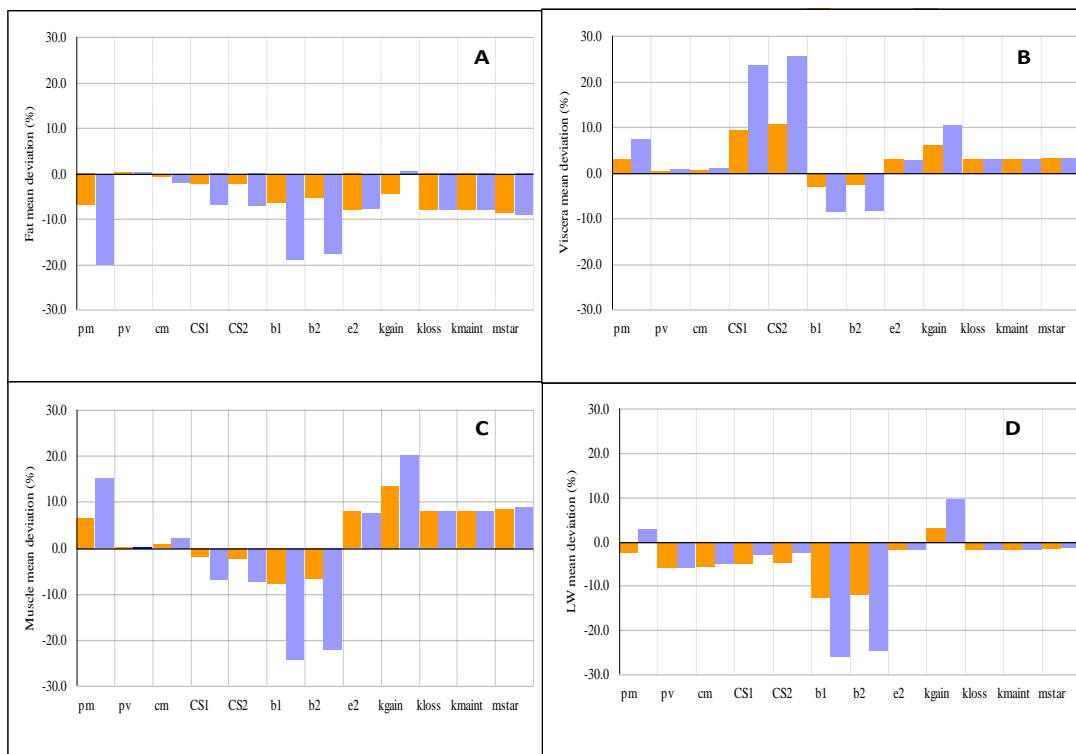
The un-optimised parameter values were taken from Oltjen *et al.* (2006) and are presented in Table 5-1. A perturbation analysis was performed to identify those parameters with significant effect on  $m$ ,  $v$ ,  $f$ , and LW. Each parameter was varied over a range of alternatives while holding the other parameters constant. Any parameter that caused a change in simulated EBW components or LW of more than one standard deviation was considered for further analysis to obtain its optimal value. Subsequently, an optimisation routine was developed to enable parameter estimation, and Kitessa (1997) experiment I data was used to fit the model to the observed LW. The optimisation algorithm was set to minimise the error sum of squares of LW weighted according to the experimental variances using the simplex method of Nelder and Mead (1965).

**Table 5.1:** Un-optimised parameter estimates of the growth and composition model of Oltjen *et al.* (2006)

Parameter <sup>2</sup>	Value	Units
$p_m$	0.3532	-
$p_v$	0.05	-
$c_m$	1340.0	kJ d <sup>-1</sup>
$CS_1$	0.314	day
$CS_2$	0.0416	day kJ <sup>-1</sup>
$b_1$	1.023	MJ d <sup>-1</sup> kg <sup>-1</sup>
$b_2$	10.54	MJ d <sup>-1</sup> kg <sup>-1</sup>
$e_2$	3.4	-

<sup>1</sup>see text for description of the parameters

Figure 5-1 shows the results of varying different model parameters by either 30.0% or 90.0% on  $m$ ,  $v$ ,  $f$ , and LW. Increasing  $p_m$  resulted in an increase in muscle mass with a larger  $p_m$  favouring more of the  $NE_g$  being directed towards muscle accumulation and a subsequent marginal increase in  $v$ . The reverse holds in the case of the fat pool with an increase in  $p_m$  reducing fat content. The decrease is at a rate equivalent to the sum of changes in muscle and viscera components. Equation 5:8 would explain this as  $NE_g$  is first used in muscle and viscera accumulation before use for fat. Increasing  $p_m$  by 90.0% resulted in values greater than one standard deviation from the original values of the components.



**Figure 5-1:** Effects (%) of varying model parameters by 30 (orange) and 90 (purple) respectively on  $f$  (A),  $v$  (B),  $m$  (C), components, and LW (D)

Increasing  $p_v$  led to marginal increases in both  $m$  and  $f$  with a slightly greater but still marginal increase in  $v$ . The parameter is responsible for the  $NE_g$  proportion for the

viscera protein component. Varying the parameter is not expected to result in significant changes since the structure of the equation in which it is used (equation 5:7) is such that changes in intake would affect  $v^*$  (equation 4:9) and  $v$  simultaneously — that is,  $v$  and  $v^*$  are used in calculating the change in  $v$  in the same equation. Varying the parameter also resulted in a notable decrease in LW.

Changing parameter  $c_m$  resulted in small increases in  $m$  and  $v$ , but a corresponding decrease in  $f$  and LW. The parameter is involved in mobilisation of body reserves to meet maintenance requirements. As expected, an animal would first mobilise fat tissue to address unmet maintenance energy cost thus resulting in a decrease in the fat pool. Subsequently, an animal would not be expected to make significant gain in muscle and viscera components from mobilising its own tissues hence the marginal increases. Furthermore, the current model is designed such that if energy intake is near maintenance, body protein can be gained and fat lost in an immature animal.

Varying  $CS_1$  and  $CS_2$  resulted in a relatively large increase in the viscera pool and decreases in  $m$  and  $f$ . This is not surprising as these parameters control the maximum weight of the viscera. Partitioning more of the  $NE_g$  to the viscera pool would leave less going to the muscle and fat components.

Varying parameters  $b_1$  and  $b_2$  had a large effect on all components and LW. For instance, increasing the two parameters by 90.0% yielded a 25.99 and 24.53 percent decrease in LW respectively. Following optimisation, the parameters changed by -3.62% and -11.51% respectively (see Table 5-1). The parameters are used in equation 5:13 to calculate  $HP_{\text{maint}}$ . This shows the importance of correctly estimating  $HP_{\text{maint}}$ ; incorrectly increasing  $HP_{\text{maint}}$  will lead to a decrease in energy available for gain.

Other variables considered for sensitivity analysis in the model included: efficiency of utilisation of ME for weight gain ( $k_{\text{gain}}$ ), loss ( $k_{\text{loss}}$ ), maintenance ( $k_{\text{maint}}$ ), and a simple exponent used in equation 5:10 ( $e_2$ ). They were considered important in parameter estimation since different animals (breeds, types, sub-types etc.) exhibit differences in these variables. As expected, increasing  $k_{\text{gain}}$  resulted in increases in all components and LW with the exception of a slight decrease in the fat pool which resulted from the 30.0% increase in  $k_{\text{gain}}$ . It is the only variable whose variation resulted in an increase in LW for both 30.0% and 90.0% increases. Varying  $k_{\text{loss}}$  and  $k_{\text{maint}}$  resulted in increases in  $m$  and  $v$  and decreases in  $f$  and LW. The decrease was larger in  $f$ . Increasing efficiency of use of maintenance energy would lead to more energy going to gain, but priority would be given to muscle and viscera before synthesis of fat. Values used by Oltjen *et al.* (2006) for  $k_{\text{gain}}$

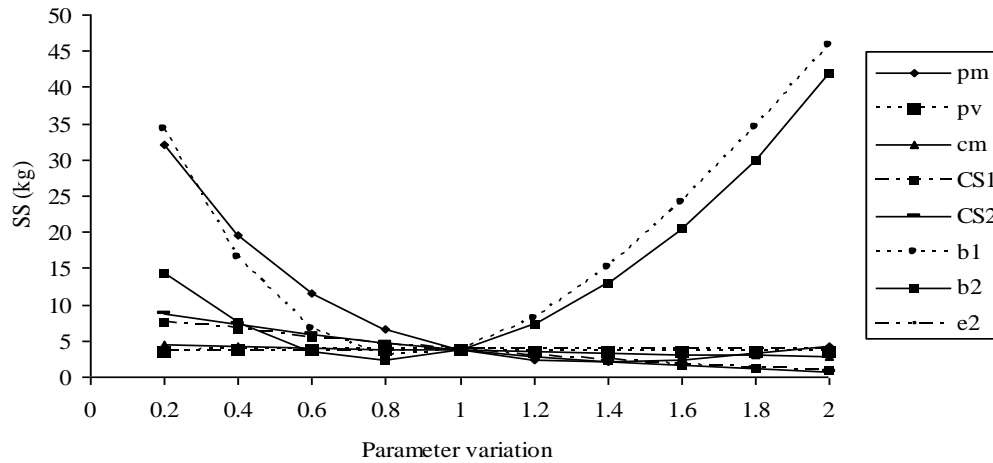
(0.4558) and  $k_{loss}$  (0.80; for  $MEI < HP_{maint}$ ) were used in this study. The values are presented in SCA (1990) feeding system. The value of  $k_{maint}$  was obtained from an equation given in SCA (1990):

$$k_{maint} = 0.5 + \left( \frac{0.02}{0.043} \right) \times k_{gain} \quad (5:18)$$

Increasing  $e_2$  resulted in an increase in  $m$  and  $v$  and a subsequent decrease in  $f$ . The decrease in  $f$  however, decreased with an increase in the parameter. It was -8.01% and -7.75% for 30.0% and 90.0% variation respectively. Increasing the exponent leads to a decrease in the rate at which an animal increases muscle mass with maturity. The parameter is involved in fat mobilisation in conjunction with the parameter  $c_m$  which is concerned with the conversion of fat to muscle when an animal is fed at or below maintenance level (see equations 5:6 and 5:10).

The value of  $m^*$  was varied to test the effect of varying the maximum DNA to reflect mature animal frame size. The rationale is to simulate smaller and larger animals as a decrease in  $m^*$  corresponds to a decrease in mature body size and vice versa. Though increasing animal size is expected to result in an increase in the weights of different EBW components and LW, this can only occur with an accompanied increase in diet allocation. In fact, the decrease in  $f$  and subsequently LW with an increase in  $m^*$  could result due to malnourished large animals mobilising their body tissue to meet maintenance energy demand. The value of  $m^*$  was obtained from David *et al.* (1996) and represented average maximum energy content of muscle component in mature Angus and Hereford cattle.

A further analysis for the effect of varying the parameters on sum of squared deviation (SS) for the data obtained from Kitessa (1997) experiment I resulted in Figure 5-2. Parameters  $p_m$ ,  $b_1$  and  $b_2$  recorded the greatest shift in SS against different levels of variations in parameter values.



**Figure 5-2:** The effect of varying parameters obtained from Oltjen *et al.* (2006) on SS for the data of Kitessa (1997) experiment I.

In light of the changes observed from variations in the current parameters for EBW components, LW and squared sum of deviations for LW, there is need to consider further parameter estimations to come up with a set of parameters that fully simulate growth and composition in the New Zealand context. The data obtained by Kitessa (1997) in experiment I were fitted dynamically (Table 5-2).

**Table 5.2:** Estimates of the growth and composition parameters for cattle based on the data of Kitessa (1997) experiment I

Parameter <sup>1</sup>	Fitted Value	Standard deviation	% change <sup>2</sup>	Units
$p_m$	0.3973	0.035	12.48	-
$P_v$	0.053	0.001	6.00	-
$c_m$	1463.65	32.42	9.23	$\text{kJ d}^{-1}$
$CS_1$	0.293	0.008	-6.69	day
$CS_2$	0.045	0.001	8.17	$\text{day kJ}^{-1}$
$b_1$	0.986	0.143	-3.62	$\text{MJ d}^{-1}\text{kg}^{-1}$
$b_2$	9.327	0.332	-11.51	$\text{MJ d}^{-1}\text{kg}^{-1}$
$e_2$	3.104	0.085	-8.71	-

<sup>1</sup>See text for description of the parameters

<sup>2</sup>See Table 5-1 for the original values

A simple correlation between model parameters was done by varying a particular parameter and obtaining the corresponding response in the parameter of interest while holding the others constant. The correlation matrix was then inverted to obtain the diagonal elements (variance inflationary factors: VIF). The VIF varied between parameters and is shown in Table 5-3. The significance of carrying out VIF analysis in relation to statistics and modelling is detailed in Marquardt (1970).

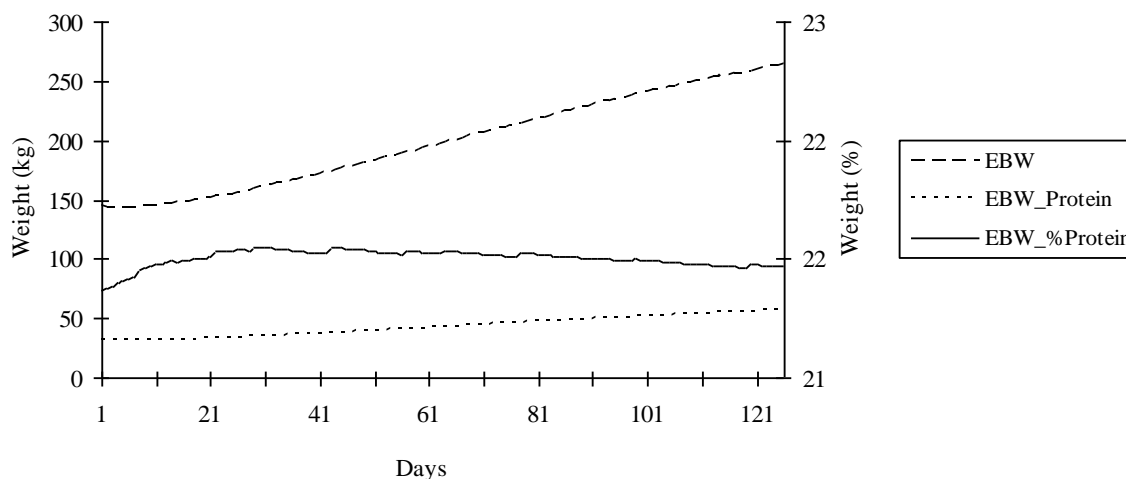
**Table 5.3:** An inverse of a simple correlation matrix amongst model parameters fitted for the Kitessa (1997) experiment I data

Parameter <sup>1</sup>	$p_m$	$P_v$	$c_m$	$CS_1$	$CS_2$	$b_1$	$b_2$
$P_v$	-0.02						
$c_m$	-0.22	0.43					
$CS_1$	0.26	-0.38	0.16				
$CS_2$	0.31	-0.87	-1.07	-0.34			
$b_1$	-0.11	0.75	0.73	0.49	-0.37		
$b_2$	0.32	-0.15	0.69	0.34	-0.57	0.00	
$e_2$	-0.31	-0.32	-0.36	0.39	0.16	-0.20	-0.20

<sup>1</sup>see text for description of the parameters

The practical implication of a model whose two parameters have a very high VIF is that the two parameters cannot be jointly estimated. Such a model is considered as over-parameterised in which case more data is required to estimate the parameters or one parameter must be dropped. Alternatively, one parameter can be set at a value determined from an independent source, i.e. from a literature search or experimentally (St-Pierre and Bywater, 1987). VIF values lower than 100 are considered acceptable in nonlinear dynamic models (St-Pierre and Bywater, 1987). However, a value of 10 was suggested by Marquardt (1970) as the upper limit in multiple linear regression contexts. The highest value obtained in this study was 0.75 implying that the current model is not over-parameterised.

Since available data for New Zealand cattle growth was on the overall growth and not the composition, a carcass-fat-to-protein ratio analysis was done to compare with results presented by Greathead *et al.* (2006). A fat to protein ratio of  $0.13 \pm 0.02$  g/kg carcass was obtained in this study. Greathead *et al.* (2006) obtained  $0.06 \pm 0.07$  g/kg carcass for animals fed dried grass and  $0.15 \pm 0.06$  g/kg carcass for animals fed silage. The current results are within the two ranges. Additionally, a test was done to establish the relationship between model EBW mass and protein (Garrett and Hinman, 1969). Model empty body weight protein and fat were converted to respective carcass weights following the results of Ferrell and Jenkins (1984) studying energy utilization by mature, non-pregnant, non-lactating cows of different types. The results for the test are presented in Figure 5-3.



**Figure 5-3:** Model EBW mass, protein and % protein

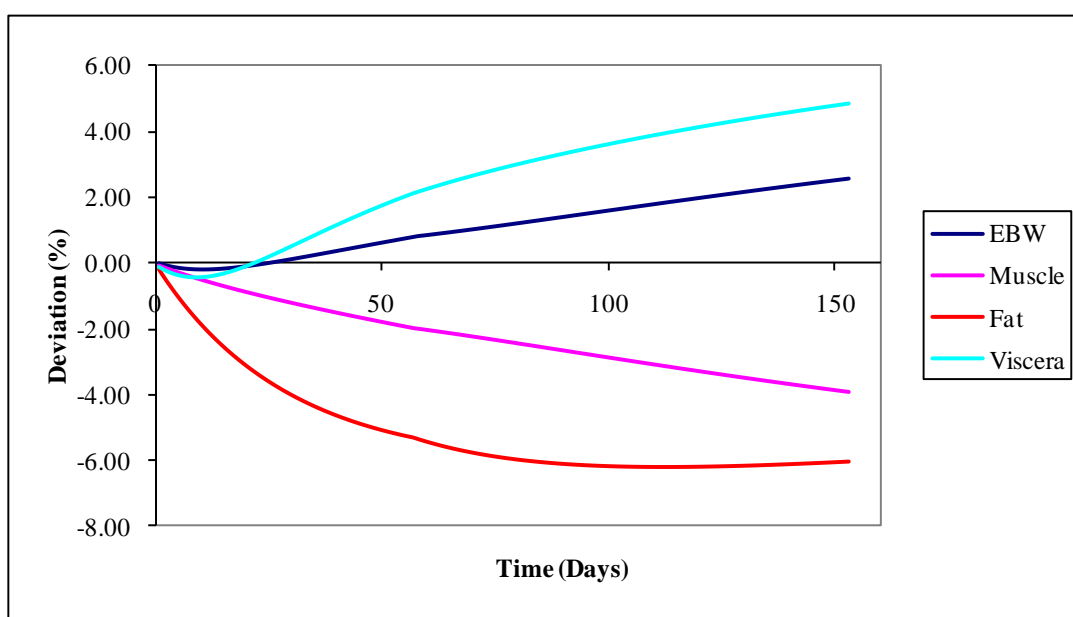
The average percentage EBW protein from the model was  $21.5 \pm 0.04$ , while Garrett and Hinman (1969) obtained a value of 22.01%. The relationship stayed relatively constant around 22.0% despite the noted increase in EBW mass and a subsequent moderate increase in EBW protein.

### 5.3. Test Simulation Two

The estimated parameters were further tested against data obtained from Sainz *et al.* (1995) in partitioning  $NE_g$  into  $m$ ,  $v$  and  $f$ . The data-set contains measurements of feed energy concentration, dry matter intake (DMI), initial and final body composition of 120 Angus-Hereford steers. The steers were fed in two phases (growing and finishing). During the growing phase, they were fed one of two diets (high or low concentrate). The high-concentrate diet was a mixed diet with a cellulose content of  $56.2 \text{ g kg}^{-1} \text{ DM}^{-1}$  while the low-concentrate diet, with a cellulose content of  $314 \text{ g kg}^{-1} \text{ DM}^{-1}$ , included alfalfa and oat hays. The low-concentrate diet ( $ME = 7.8 \text{ MJ kg}^{-1}$ ) was available *ad libitum* (FA) and the high-concentrate diet ( $ME = 12.8 \text{ MJ kg}^{-1}$ ) was either available *ad libitum* (CA) or limited (CL) to match the weight gains of the FA group. During the finishing phase, steers were fed the high-concentrate diet, either for *ad libitum* intake (CA) or restricted to 70.0% *ad libitum* intake (CL). This resulted in five groups of different growth paths: CA-CA, CL-CA, CL-CL, FA-CA and FA-CL. An additional group was slaughtered at the beginning to allow estimation of the initial body composition of the steers. Values for initial EBW and its components were set to correspond to the values reported in Sainz *et al.* (1995). This was 214.0 kg for EBW, 36.74 kg  $m$  and 25.2 kg  $f$ . The value of  $m$  was obtained by subtracting  $v$  from total protein. Initial  $v$  weight was assumed to be 6.0% of the LW (Soboleva *et al.*, 1999) which is 16.58% of the

sum of the liver, heart, kidney, spleen and gastrointestinal tract weight (Oltjen *et al.*, 2001).

Figure 5-4 presents percentage difference between model EBW mass and its components using parameters obtained in this study and those used in Oltjen *et al.* (2006). Parameters obtained in this study were estimated against New Zealand data which came from grazing animals (Kitessa, 1997) while parameters obtained by Oltjen *et al.* (2006) mainly came from stall-fed animals (Hoch *et al.*, 2005 and Sainz *et al.*, 1995). There were slight differences for the EBW mass with the highest difference of 2.59% being observed in day 153 of the model outputs. The fat component differed most with a value of -6.18%, followed by viscera at +4.84% and a maximum difference of -3.96% for muscle (CA-CA treatment group).



**Figure 5-4:** Percentage difference between model EBW mass and components using parameters obtained in the current study and those used in Oltjen *et al.* (2006)

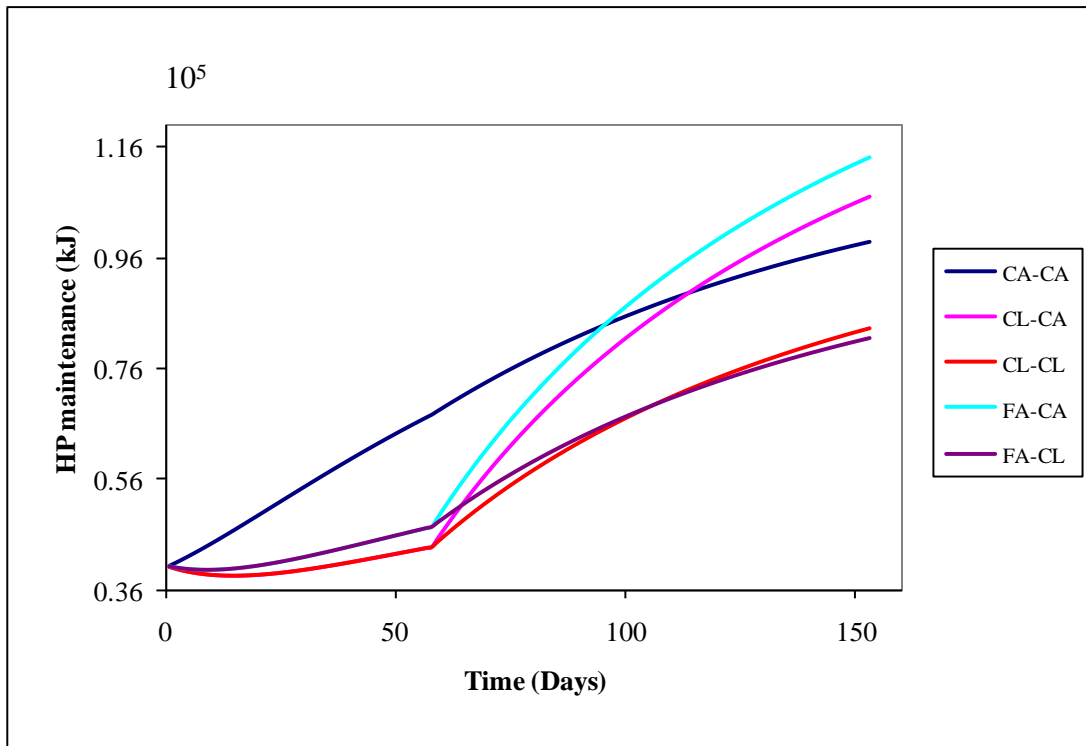
In all cases, fat and muscle components were lower with the revised parameter set while this was the case with EBW and viscera for the first 20 days of the simulation followed by higher values for the remaining period. This trend was expected especially for the fat and muscle components since feed for stall-fed and grazed animals tend to differ in quantity and form of ME, both of which are important determinants of animal performance (Steen and Robson, 1995). Furthermore, Steen and Moore (1988) reported that animals fed silage have high carcass fat to protein ratio following an observation by Gill *et al.* (1987) that protein deposition was limited in animals fed grass silage.

Livestock production in New Zealand is based on pasture and forage for all classes of ruminants (Waghorn and Clark, 2004). These pasture and/or forage dependent production systems are constrained by the amount, seasonality and annual variability of forage

production (Oesterheld *et al.*, 1992; Diaz-Solis *et al.*, 2006). Due to the varying feed quantity and quality, grazing animals are either subjected to periods of restricted or excess dry matter intake. This introduces the phenomenon of compensatory growth which has been documented by Nicol and Kitessa (1996) for beef cattle in New Zealand. Thus, a beef growth and body composition model designed to simulate cattle growth and composition in such production systems should be sufficient to take into consideration the effect of compensatory growth for grazing animals following changes in ME intake. A lag in maintenance requirements following the changes is expected since the requirements and heat production are related to intake (Oltjen *et al.*, 2006). Figure 5-5 shows  $HP_{\text{maint}}$  for steers receiving different MEI treatments assuming growing and finishing phases of 57 and 96 days respectively (Sainz *et al.*, 1995). It is notable that the model is able to simulate the dynamic nature of variable maintenance. A similar pattern in the resulting curves has been reported (see Figure 15.12 in Oltjen *et al.* (2006)) in regard to the maintenance coefficient as a function of time ( $\alpha_t$ ). The coefficient was used in calculating  $HP_{\text{maint}}$  in that study as:

$$HP_{\text{maint}} = \alpha_t \text{EBW}^{0.75} \quad (5:19)$$

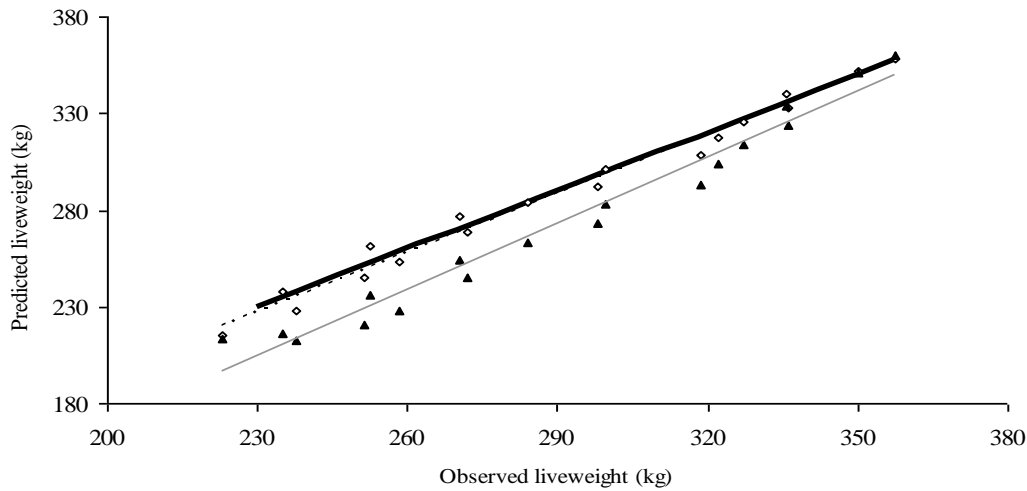
The value of  $\alpha_t$  and subsequently  $HP_{\text{maint}}$  was highest in animals subjected to high MEI following a severe restriction (LS in Oltjen *et al.* (2006)). The trend was observed in this study with FA-CA resulting in the highest value for  $HP_{\text{maint}}$  (see Figure 5-5) followed by CL-CA and the least was from animals whose MEI was varied from low to medium (FA-CL).



**Figure 5-5:** Model-predicted Hp for maintenance for five treatment groups of Sainz *et al.* (1995)

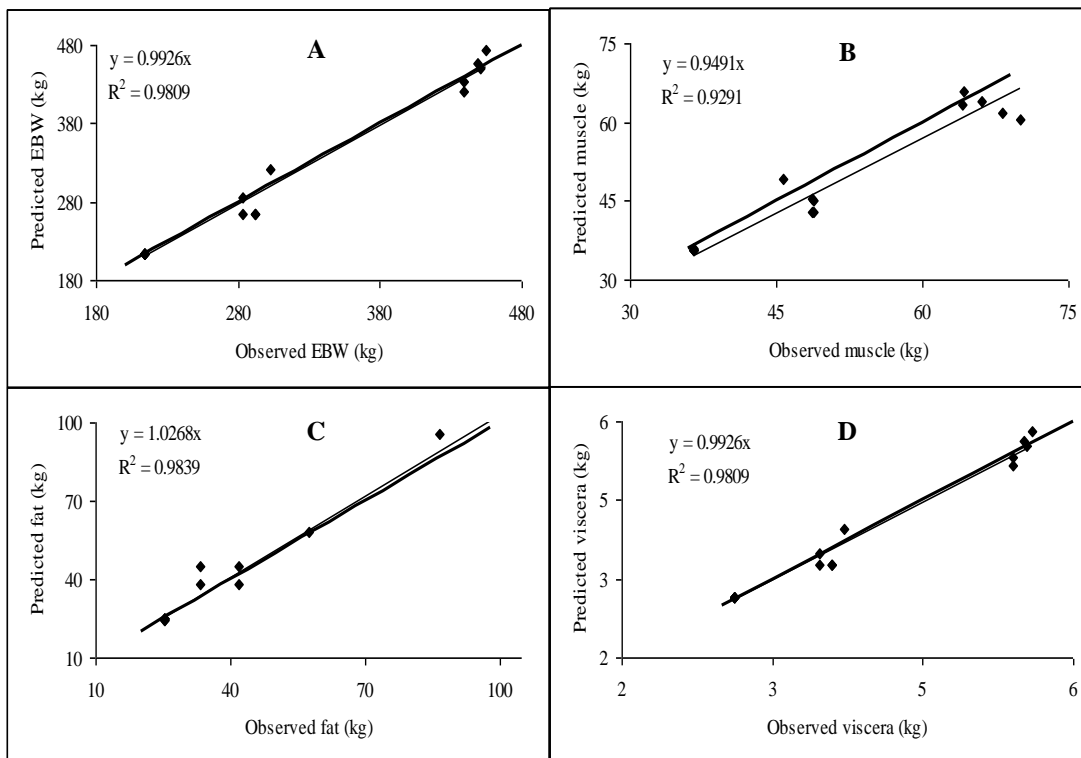
#### 5.4. Beef Growth and Composition Model Performance Evaluation

Figures 5-6 and 5-7 show plots of observed and predicted values using parameters obtained from Oltjen *et al.* (2006) and the set obtained in this study for the average LW from the data of Kitessa (1997) experiment II and Sainz *et al.* (1995) respectively. From Figure 5-6, it is evident from the resulting curves that the parameters estimated in this study predicted New Zealand beef growth and composition better than those used by Oltjen *et al.* (2006). This was expected since the current study utilised data obtained from New Zealand grazing cattle experiments.



**Figure 5-6:** Observed and predicted values for average LW for animals in data obtained from Kitessa (1997) experiment II utilising published parameters in Oltjen *et al.* (2006),  $\blacktriangle$  \_\_\_; and parameters estimated in this study,  $\circ$  -----. The thick line is the  $y=x$

Figure 5-7 further shows that the model has a good prediction of EBW mass (Figure 5-7A; bias = -0.008), m (Figure 5-7B; bias = -0.0509), f (Figure 5-7C; bias = + 0.0268) and v (Figure 5-7D; bias = -0.008) components of the EBW.



**Figure 5-7:** Observed (Sainz *et al.*, 1995) and predicted values for EBW mass (A), muscle (B), fat (C) and viscera (D). The thick line is the  $y=x$

Table 5-4 shows the comparison of model predictions and data of Sainz *et al.* (1995) and their respective percentage differences for EBW, protein, f and v components. Percentage differences obtained between the prediction and data shows that the model reproduces well

the experimental results for the parameter values presented in Table 5-2 for EBW mass and its components.

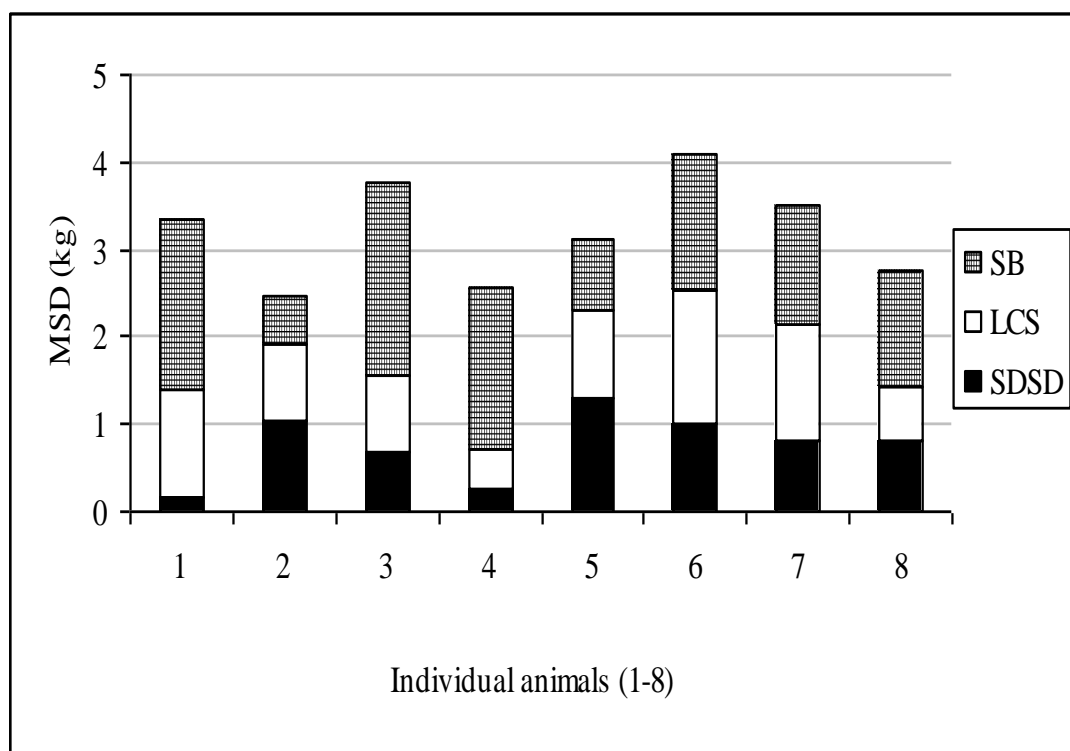
**Table 5.4:** Comparison of model predictions (Pred.) and data of Sainz *et al.* (1995) (Obs.) and their percentage differences (% dif.) for EBW, protein, fat and viscera components of the final slaughter group

Treatment <sup>2</sup>	EBW (kg)			Protein <sup>1</sup> (kg)			Fat (kg)			Viscera (kg)		
	Obs.	Pred.	% dif.	Obs.	Pred.	% dif.	Obs.	Pred.	% dif.	Obs.	Pred.	% dif.
CA-CA	451.0	450.89	-0.02	69.7	68.88	-1.17	116.7	109.99	-5.75	5.54	5.53	-0.018
CL-CA	449.0	457.77	2.03	71.6	69.76	-2.57	106.9	112.05	4.81	5.51	5.62	1.95
CL-CL	439.0	433.46	-1.26	73.6	67.21	-8.69	96.5	101.05	4.72	5.39	5.32	-1.30
FA-CA	455.0	473.96	4.16	69.80	71.56	2.52	116.4	119.43	2.61	5.59	5.82	4.18
FA-CL	439.0	420.72	-4.16	75.40	65.83	-12.69	86.60	95.32	10.06	5.39	5.17	-4.14

<sup>1</sup>Protein equals the sum of m and v

<sup>2</sup>See text for the treatments description

Figure 5-8 shows mean squared deviation (MSD) and its components for eight individual animals in Kitessa (1997) experiment II. Results for animal 6 showed the largest MSD, for which the squared bias (SB) and lack of correlation weighted by the standard deviation (LCS) were equally distributed (approximately 1.5 kg each). In general, squared difference between standard deviations (SDSD) contribution to the MSD varied amongst the cases. The SDSD was smaller in 62.5% of the 8 cases (animals 1, 3, 4, 6 and 7) while SB was smaller in 25.0% of the cases (animals 2 and 5). The MSD indicates the overall deviation of the model output from the measurement while the components represent different aspects of the deviation as detailed in section 2.9.



**Figure 5-8:** Mean squared deviation (MSD, kg) and its components; lack of correlation weighted by the standard deviation (LCS), squared difference between standard deviations (SDSD), and squared bias (SB) in comparison of LW simulations for 8 different animals

The basis of carrying out the results presented in Figure 5-8 was to show that the model had no systematic bias on any component of the difference between measured and simulated values as this would have resulted in similar pattern for animals 1-8.

### **5.5. Incorporation of the Beef Sub-model in LincFarm Model**

The beef growth and composition sub-model described in this chapter was used to extend the LincFarm grazing sheep model for simulation of dryland sheep-beef grazing systems. Various tests were carried out to ensure the revised model incorporating the beef sub-model performed as expected by replicating the simulations described above. The tests involved comparing the extended model output with those of the stand-alone beef sub-model for LW, EBW, protein, fat and MEI. In all test cases, the output of the incorporated beef sub-model and the stand-alone beef model were equal. Consequently, the incorporated beef sub-model was considered to be suitable for simulating growth and composition for growing beef cattle in New Zealand.

Management events such as buying cattle onto the farm, replacement and selling policies, hay feeding, grazing rules and allocation of blocks (for grazing or standing when being fed hay) were tested to ensure that they would be applicable to the beef herd. For all possible scenarios tested, results showed that the beef model had been successfully incorporated into LincFarm and was working as expected.

### **5.6. Conclusion**

It is concluded that the stand-alone beef sub-model as incorporated in LincFarm is sufficient to model New Zealand beef growth and composition utilising parameters estimated from available data. The results from this study further confirm the suitability of the Davis Growth Model (DGM) in simulating ruminant growth and composition. However, there is a need to consider parameter estimation to address the growth characteristics of animals in a particular production system when utilising the DGM.

In addition to the beef model and the pasture and crop growth models described in the previous chapter, the final component required in LincFarm for the current study is a destocking and marketing algorithm to allow tactical responses to climatic variability as it unfolds. This is described in the following chapter.

## CHAPTER 6

### A Destocking and Marketing Algorithm

#### 6.0. Introduction

As noted previously, dry land farming on the east coast of New Zealand is subject to significant climatic variability. In the location of this study on the Canterbury plains, winters are normally cool and wet and summers warm and dry, although not always so. Spring and autumn can either be wet or dry, warm or cool. The *typical* pattern of pasture growth is one of very low growth during winter because soil temperatures are too low even though there may be sufficient moisture, accelerating growth from mid August as soil temperatures start to increase, reaching a peak around October/November followed by an abrupt drop in growth as soils dry out because of a lack of rainfall in summer (anytime from October onwards), a resurgence of growth with the autumn rains in April/May and a return to low growth again as temperatures drop from June onwards. However, spring growth may be delayed because of cooler or dryer conditions than are typical; spring/summer growth may cease early if there is little rainfall after September or it may continue throughout the season if there is a wet summer; there may or may not be autumn rain. Drier, cooler conditions early in the season (September/October) *may* be followed by wetter, milder conditions later (November/December) so that growth patterns can be almost reversed. There have been some years, such as the 1988-89 drought mentioned in the introduction, when there was no rain for 18 months.

From a pastoral livestock perspective, there is generally adequate grass growth in most years to support production from August through to anytime after October when soils dry out and grass growth stops. This provides a 3 to 5 month 'window of opportunity' for production and most farmers aim to lamb in August/September and have the majority of their lambs finished before Christmas. There is the very strong possibility that lambs remaining on the farm after December will not grow well because of inadequate feed quantity or quality, and with typically falling prices from November onwards, it is often better to sell lambs as store stock early than keep them in the hope of finishing them for the works, only to be forced to sell them as stores later.

From a production and profitability perspective then, perhaps the most difficult period of uncertainty and risk is the time at which conditions dry out in spring/summer and grass growth ceases. Most commentators note that farmers generally wait too long to respond to drying conditions in the hope that there will be some rain, grass growth will recover and they

will be able to put more weight on their lambs before sale. The second most difficult period is autumn in terms of providing adequate feed quantity and quality to flush ewes to ensure high lambing percentages in the following season. This can be exacerbated if lambs are retained, grow slowly over summer, are held too long and start to compete with ewes for the best available feed during flushing.

Decisions on the stock type and number of animals of each type to retain on the farm introduces a complexity in managing the grazing system to achieve optimal productivity and profitability due to this seasonality and annual variability of forage production. Timely decision-making and subsequent actions are crucial to the survival and profitable running of high performance dryland grazing sheep systems in these climatic conditions.

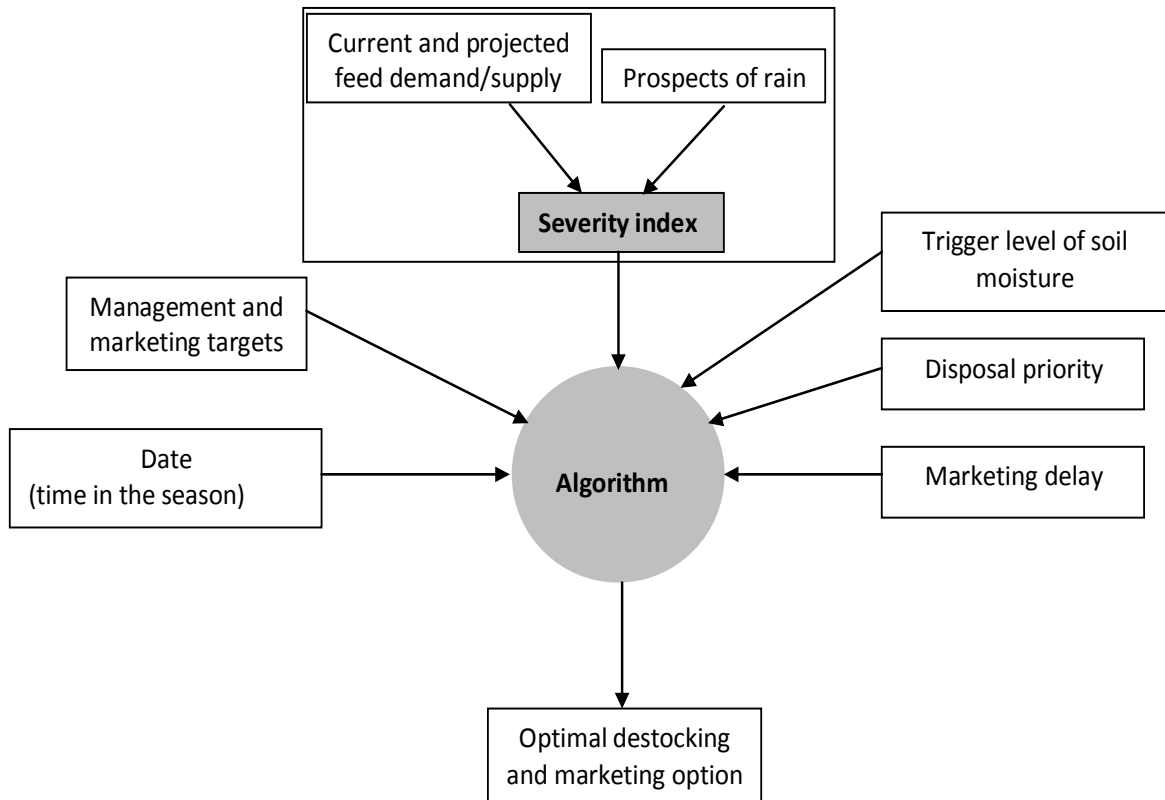
In order to evaluate different tactical responses to climatic conditions in this situation, an algorithm has been developed to carry out destocking and marketing decisions where productivity and profitability are highly influenced by climatic variability. The algorithm is designed to be actioned when soil moisture level reaches a predetermined trigger value indicating the (temporary) cessation of pasture growth and to respond to an assessment of current feed availability on the farm and the prospect of rainfall which will stimulate utilisable pasture growth in time to feed the animals on hand.

## **6.2. Design, Development and Implementation of the Destocking Algorithm**

A generic destocking and marketing algorithm was designed and implemented to assist in making tactical destocking and marketing decisions. The aim was to evaluate the effects on productivity and profitability of alternative management responses to different scenarios with respect to feed availability and current and prospective climate conditions, and different trigger values defined as different levels of soil moisture.

Figure 6-1 shows diagrammatic representation of the algorithm. Based on the time of the season, the target trigger level for soil moisture, current and projected feed demand/supply, prospects of rain, severity index and producer defined stock disposal priority, the algorithm calculates the optimal destocking and marketing option. Tests run from left to right of the diagram. The algorithm loops back to the beginning (time in the season) whenever a condition is not met (for example a value below the desired date when destocking and/or marketing action(s) should be activated). The algorithm repeats the process after a defined period (for example, 7 days from the last test date).

Illustration 6-1 below shows the pseudo code implementation of the destocking algorithm.



**Figure 6-1:** The destocking and marketing algorithm

**Definitions:**

$T_i$ : series of decision times

$M_i$ : soil moisture at time  $T_i$

TM: target moisture

$TM_{Levels\ 1-3}$  are 10, 12.5 and 15% of the top 25 cm soil respectively

$S_{ji}$ : stock class  $j$  on the farm at time  $T_i$

where  $j=1, \dots, 5$  represents capital ewe, lambs, cull ewes, 1<sup>st</sup> cycle ewes, and cattle stock classes respectively

$N_{ji}$ : number of animals in stock class  $j$  at time  $T_i$

$F_i$ : farm feed supply at time  $T_i$

$R_{ji}$ : corresponding stock class feed requirement at time  $T_i$

$D_{ji}$ : total animal feed demand at time  $T_i$

$$D_{ji} = \sum_{j=1}^5 R_{ji} \times N_{ji}$$

$PR_i$ : the probability of substantial rain falling at time  $T_i$

where  $PR_i$  is one of high, medium or low defined as follows:

High: High chance that a rain event occurs and that the amount is enough to cause pasture growth that can sustain animals on a farm

Medium: Moderate chance that a rain event occurs and that the amount is enough to cause pasture growth that can sustain animals on hand

Low: Low chance that a rain event occurs and that the amount is enough to cause pasture growth that can sustain animals on hand

$SI_i$ : severity index at time  $T_i$

where  $SI_i$  is one of high, medium or low defined as follows:

High: feed days available limited and chance of substantial rain falling low

Medium: feed days available limited and chance of substantial rain falling moderate  
 Or  
 feed days available unlimited and chance of substantial rain falling low  
 Low: feed days available unlimited and chance of substantial rain falling high

$P_{ki}$ : stock class corresponding to feeding priority  $k$  at time  $T_i$   
 where  $k = P_{k1-5}$  is  $S_{j1}$ ,  $S_{j2}$ ,  $S_{j3}$ ,  $S_{j4}$  and  $S_{j5}$  and  $S_{j1}$ ,  $S_{j2}$ ,  $S_{j5}$ ,  $S_{j4}$  and  $S_{j3}$  for pre- and post weaning respectively

$A_{di}$ : destocking action  $d$  at time  $T_i$   
 where  $d=1, \dots, 3$  represents destock heavily, low to moderate destocking and do not destock now respectively

#### Algorithm

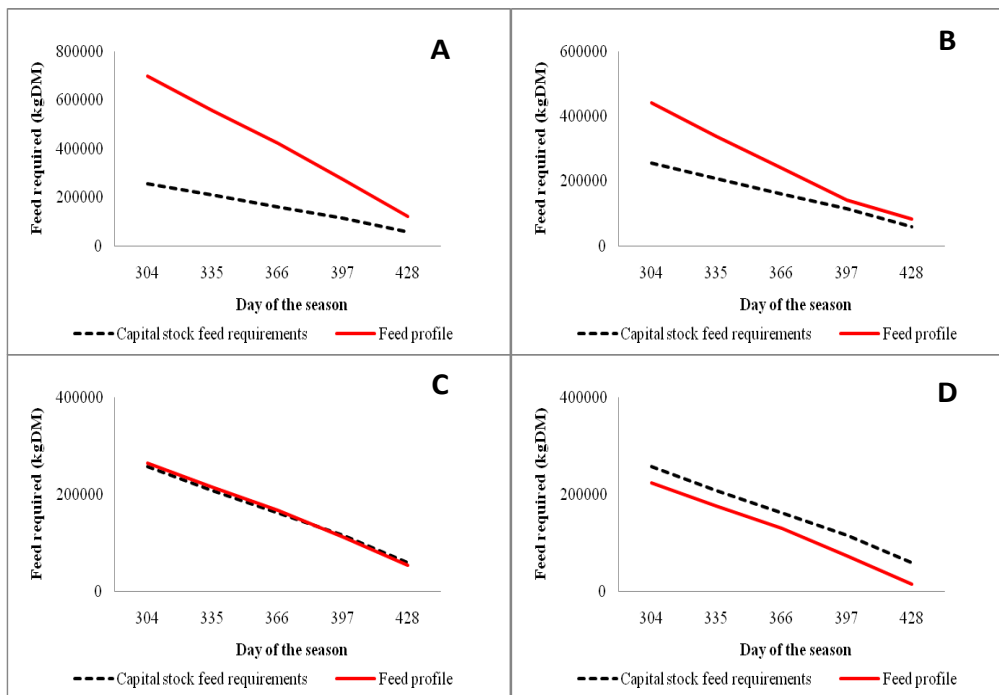
```

Function destock()
  For times  $T_i, =0, \dots$ , end in steps of 7 days
  If soil moisture ( $M_i$ ) < target ( $TM_i$ ) then
  Calculate  $F_i$ 
  Calculate  $D_{ji}$  for each stock class  $j$  from  $T_i$  to  $T_{i+1}$ 
  Calculate total animal feed demand ( $\sum D_{ji}$ )

  Evaluate feed situation (compare total animal feed demand with  $F_i$ )
  Get the probability of substantial rain falling ( $PR_i$ )
  Calculate the severity index ( $SI_i$ )
  If  $SI_i$  is equal to high then
    Destock heavily ( $A_{d1}$ )
  Else if  $SI_i$  is equal to medium then
    Apply low to moderate destocking ( $A_{d2}$ )
  Else if  $SI_i$  is equal to low then
    Do not destock now ( $A_{d3}$ )
  Else do nothing
  Return output
  
```

#### Illustration 6-1: Destocking algorithm

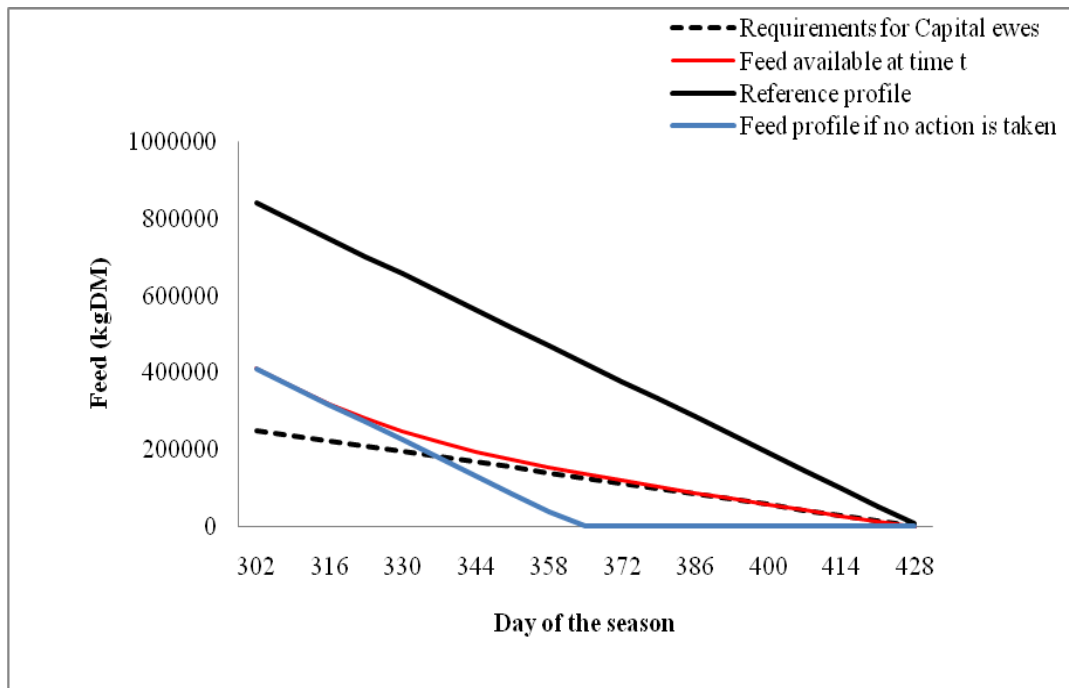
Running the destocking and marketing algorithm under four potential feed scenarios on a given farm resulted in Figure 6.2. Figure 6-2A represents a scenario where feed available is more than enough to feed all stock types on the farm, Figure 6-2B shows a feed situation where the farmer can feed the capital stock sufficiently and remain with some feed which can be utilised by a proportion of non-capital stock. Under the scenario depicted by Figure 6-2C, the producer would only be able to retain the capital stock on the farm as the feed available is just enough to meet the requirements of those stock. The situation represented by Figure 6-2D means the farmer has either to buy supplementary feed for the breeding stock (capital stock) if a decision is made to retain part or all of the capital stock on the farm, sell a certain proportion of the stock or acceptably underfeed the capital stock. There is also a possibility of combining any two or more of the response noted above to reduce capital stock feed demand on the farm.



**Figure 6-2:** The four potential animal feed demand and supply scenarios (A, B, C and D) under a grazing system

Scenarios A, C and D are easier to deal with than scenario B. For instance, in case A, non-capital stock would be sold according to the desired target drafting weight and any extra feed could be sold or conserved for future use. Feed circumstances described by scenario C dictates that the producer can only feed the capital stock and so any other stock on the farm has to be disposed if the cost of buying feed to maintain them is greater than the benefits (i.e. loss avoidance). Under scenario D, feed has to be bought into the farm to feed the capital stock. The other alternative would be to sell a part of the capital stock to release feed required to take the remaining number of animals on the farm to the end of the season.

The feed profile for scenario B can be considered to fall between scenarios A and C, allowing it to be defined within maximum and minimum constraints. Figure 6-3 shows the minimum (requirements for capital stock) and maximum (reference profile) constraints. The area between the two constraints represents the feed needed to supply nutrients required for non-capital stock to the end of the season. The minimum constraint is more important since it is the minimum feed required to supply the capital stock to ensure acceptable levels of (re)production in the following season.



**Figure 6-3:** Results from the destocking and marketing algorithm feed profiles

The curves presented in Figure 6-3 were obtained from implementing the destocking and marketing algorithm. There are two options available to a farmer faced with feed scarcity as shown in Figure 6-3. At any given point in time when conditions dry out, depending on the current feed demand and supply and the prospects of receiving sufficient rainfall to generate enough pasture growth to supply the anticipated feed deficit, the farmer could retain the stock on hand and follow a predetermined marketing policy to the end of the season or until conditions dry out again. However, if there is little prospect of rain falling and the feed available cannot carry the stock on hand to the end of the season, the producer may opt to destock to match the feed demand and supply. For the example presented here, the farmer would only be able to retain stock on hand for 61 days (between day 304 and 365) if no action is taken to destock the farm and there is no rain. If on the other hand the farmer's decision is in fact to destock the farm, the algorithm should ensure that the feed available is utilised optimally i.e. no feed remains on the farm at the end of the season following destocking. Optimal solutions should map the feed profile curve as close to the minimum constraint as possible following destocking. The current algorithm was able to satisfy this requirement as no feed remained on the farm at the end of the season (the 28<sup>th</sup> February; in the context of this study) as shown in Figure 6-3 (feed available at time t).

### 6.2.1. Inclusion of a 'Severity Index'

The combined effect of current feed demand and supply and the probability of sufficient rain falling to stimulate pasture growth was incorporated in the algorithm by

developing a Severity Index (SI) as a guide to how aggressive the farmer should be in responding to any given situation.

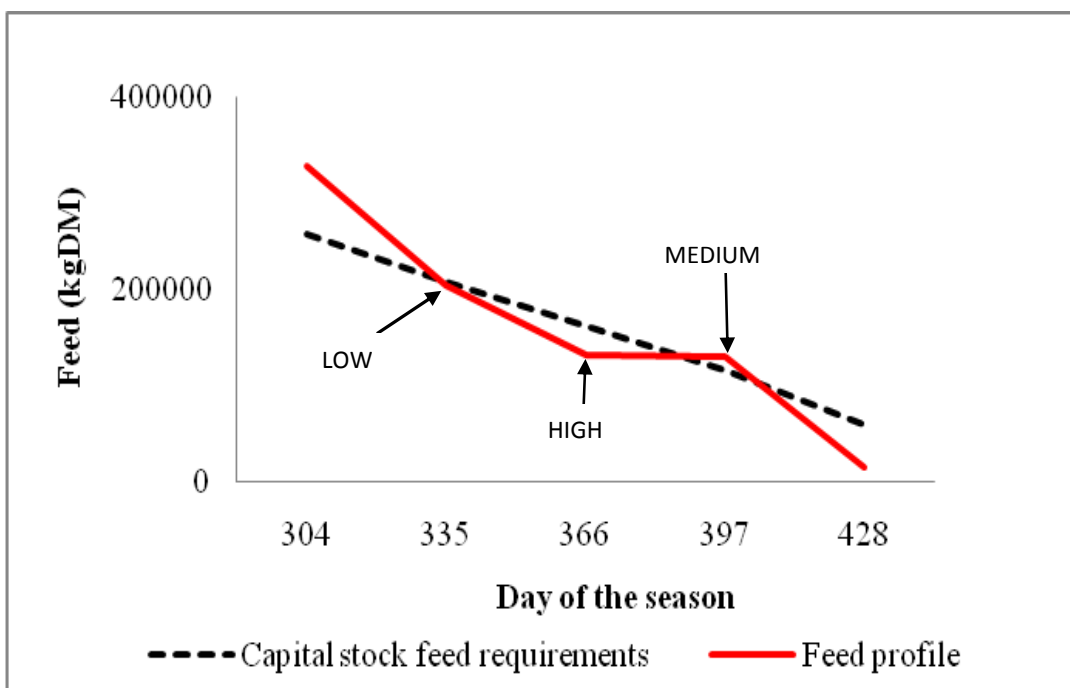
Soil moisture level is a balance between the addition of water (through rainfall or irrigation) and loss through evapo-transpiration. If there is no rain falling or irrigation being applied to replace the lost water, the soil moisture falls to the extent that plants reduce growth and ultimately wilt and die (MAF, 2010a). A survey presented by MAF (2010b) indicates that at least 65.0% of farmers take current crop condition and forecasted weather into consideration with respect to the state of the soil moisture on their farms for the purposes of feed planning. The survey concluded that the majority of farmers considered the state of the soil and the crops, and how the two might change given the weather forecast in their management decision making. This approach was used to develop the SI. In addition to the soil and pasture conditions and weather forecast, a feed budget to the end of the season is calculated. This ensures that the index is not just responsive to the current feed situation but rather to the combined effect of the current and prospective feed supply/demand situation and the possibility of receiving rainfall.

The algorithm is designed to scan rainfall forecasts for a user defined number of days ahead of the test day. With the rain forecast obtained, an approximation of the quantity of additional feed resulting from the rainfall is made. An analysis is then done to determine whether the feed at hand is enough to carry the animals at hand to a time when the projected feed resulting from the rainfall event(s) is available, and this modifies the SI. It is important to note, however that the prospect of rainfall does not change the amount of feed available at the test day, rather it results in an approximation of feed available at and after the time the rainfall event(s) occurs. Weather forecast data are readily available in New Zealand from the National Institute of Water and Atmospheric Research Ltd of New Zealand (NIWA). Where the algorithm is used as a standalone decision aid, forecasts of the prospect of receiving rainfall in a future period are assumed to be obtained from NIWA. In the context of the simulation, a 28 days rainfall forecast was utilised but due to the fact that the study was based on historical weather data for the 19 years of analysis, it was assumed that rainfall records for 28 days after the test day were indicative of such a forecast. The 'forecast' was thus read from climate data input files. Note that the severity index has no bearing on the calculation of current feed demand or supply, it simply alters the aggressiveness or otherwise of the response to the current feed situation.

Three levels of severity are defined in the index as low, medium or high. For independent use by farmers, a severity ranking can be assigned by the user according to their

production circumstances and experience. But generally, if the farm feed situation and/or the prospect of rain falling is good, severity is considered low. The reverse holds for high severity. Given an evaluation of the severity, the algorithm responds differently in terms of destocking. For instance, if the severity is low, even if the feed available cannot carry the stock on hand to the end of the season, animal disposal can be delayed which may result in feed available falling below the minimum constraint trajectory.

Figure 6-4 shows a feed profile curve resulting from a sequential evaluation of the algorithm behaviour in the light of encountering the three potential levels of severity. The assumption is that in areas with high climatic variability, it would be possible to experience two or three SI circumstances within a season. The shape of the resultant curve shows the algorithm is able to respond dynamically to varying severity index levels within a season. At the point marked high on the curve, the algorithm ranks the pasture availability and rainfall probability situation as highly severe, resulting in a heavy destocking (sharp rise noted on the feed profile curve at the decision point) to correct the situation. Under a situation of medium severity, it would be expected that only a certain proportion of the non-capital stock would be retained on the farm since the index is assigned relative to feed demand and supply. This means that the anticipated rainfall and/or current feed situation would still be limiting but to a lesser degree compared to the high severity scenario. Under low severity it would be possible to retain all non-capital stock and follow the target marketing strategy, assuming the low severity status is maintained through the season.



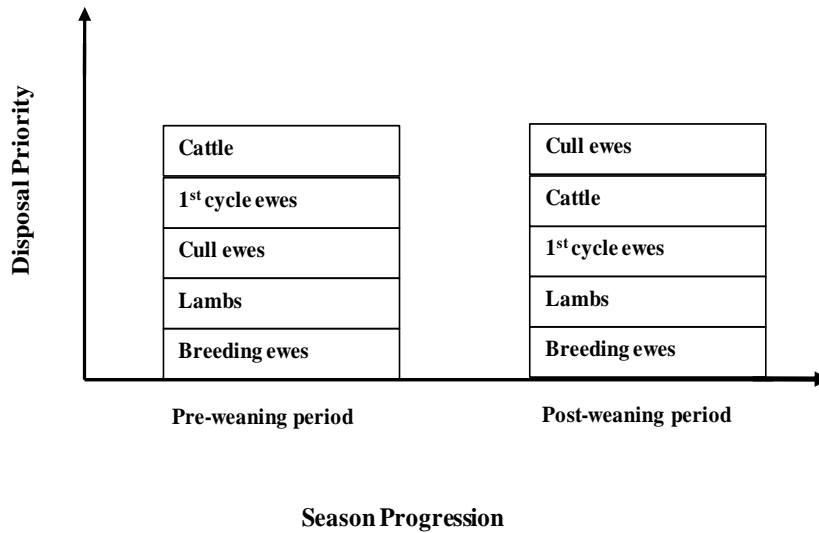
**Figure 6-4:** Feed profile for a farm situation where the three severity circumstances are encountered as indicated on the graph

### ***Testing the Destocking and Marketing Algorithm***

A hypothetical farm was defined and different feed scenarios tested using the destocking and marketing algorithm. The farm's overall objective was to maximise productivity and profitability through finishing as many lambs as possible. The farm had a total of 1099 ewes divided into a main ewe mob and a 1<sup>st</sup> cycle ewe mob tupped to lamb three weeks earlier. The total number of ewes in the 1<sup>st</sup> cycle ewe mob (older ewes) was set at 241 or approximately 22.0% of the entire ewe flock. It was also assumed that culling occurred at 16.0% of the total ewes on the farm which totals approximately 176 ewes. The 1<sup>st</sup> cycle ewes were either selected from the cull ewes considered to be in good condition or sourced from outside the farm through purchase. The combined lambing percentage for both ewe mobs was taken to be 155.0% which translates to approximately 1700 finishing lamb assuming no lamb losses occur pre- or post-parturition. In addition to the sheep flock, a total of 120 head of cattle were bought onto the farm in autumn (during May). The cattle and old ewes were considered to provide flexibility options for risk management and could be sold off at any time depending on the feed situation on the farm.

The key options available to a farmer for balancing feed supply and demand in a grazing system in the face of climatic variability partly relate to animal categories on the farm and the economic efficiency of retaining a particular stock type for a longer period on the farm. The first consideration is normally to supply the capital stock (breeding ewes) with sufficient feed to maintain acceptable levels of future (re)production performances before considering retaining any other stock type. Figure 6-5 shows stock type retention priorities for the hypothetical farm as the season progresses.

These stock disposal priorities are based on the policies adopted by the Silverwood farmer reference group for operation of the Silverwood innovative sheep systems trial (Bywater *et al.*, 2010). Further details of the philosophies and operating policies for the farm units included in this trial are presented in Chapter 7.



**Figure 6-5:** Stock type disposal priority for the hypothetical farm with the progression of the season

It was considered more economically efficient to keep un-weaned cull ewes and their lambs for longer than growing cattle when faced with a feed deficit prior to weaning as shown in Figure 6-5 due to the benefits obtained through higher growth rates from suckling lambs. However, once the main mob is weaned, it is more profitable to sell off the cull ewes compared to selling the growing cattle which have the potential to continue gaining weight. In a scenario where cull ewes have been sold and a producer faces a feed deficit and the only potential stock types available for disposal includes growing cattle and lambs, it would be more economically efficient to sell the growing cattle. In extreme cases, such as is in a developing drought situation, the producer's choices are limited after sale of all disposable stock types (that is— cull ewes, cattle and lambs) and the only options would be to (i) buy feed to supplement breeding stock (capital stock) if a decision is made to retain all or part of the capital stock on the farm, (ii) sell all or part of the stock or (iii) acceptably underfeed the capital stock which can be also considered as the wait and see strategy (A.C. Bywater, pers com).

Table 6-1 shows sample potential decision rules for the hypothetical farm based on different feed and moisture level circumstances. The table is divided into 4 sections. Items in the top two sections represent a list of conditions to be tested and the respective condition values. Items in the bottom two sections show the list of potential actions and the actions taken in response to results from the tested conditions. The sample lists a total of 17 distinct decision rules each represented by a column. Each decision rule (column) is a unique combination of a set of conditions-value(s) and the action(s) to be taken correspondingly. For

instance, the first decision rule tests whether tailing has occurred. If tailing has not been carried out, the algorithm loops back to test tailing after a period of 1 week. However, if tailing has occurred, it proceeds to test whether the current date is less than 31<sup>st</sup> October. If current date is less than 31<sup>st</sup> October, a soil moisture test is carried out and compared to target trigger values of 10.0, 12.5 and 15.0% by volume in the top 25cm of soil. A value below any of the target trigger values causes the algorithm to do a feed profiling analysis giving dates when destocking should be done to make it to the end of the season. A moisture level above the target trigger values causes the algorithm to divert from the feed profiling analysis to a test aimed at establishing the proportion of lambs whose weight is greater than the target drafting weight (DW) for drafting.

**Table 6.1:** Destocking and marketing policies decision rules table for the hypothetical farm

Destocking responses	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Tailing has occurred?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Current date < 31 <sup>st</sup> October?	-	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
Soil moisture below target level?	-	N	Y	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-
Enough feed for capital stock to a target time in the season?	-	-	Y	Y	N	-	-	-	-	-	-	-	-	-	-	-	-
Enough feed for non-capital stock to a target time in the season?	-	-	Y	N	-	-	-	-	-	-	-	-	-	-	-	-	-
10% of the lambs > Target DW?	-	-	-	-	-	N	Y	N	Y	N	Y	N	Y	-	-	-	-
Lamb avg wt > Target WW?	-	-	-	-	-	N	N	Y	Y	N	N	Y	Y	-	-	-	-
Current date < 15 <sup>th</sup> December?	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
Current date > 15 <sup>th</sup> December?	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	Y
Soil moisture below target level?	-	-	-	-	-	N	N	N	N	Y	Y	Y	Y	-	-	-	-
Enough feed for capital stock to a target time in the season?	-	-	-	-	-	-	-	-	-	Y	Y	N	N	Y	N	Y	N
Enough feed for non capital stock to a target time in the season?	-	-	-	-	-	-	-	-	-	Y	N	-	-	Y	-	Y	-
Current date < 28 <sup>th</sup> February?	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N	-
Buy feed or sell part of the capital stock	-	-	-	-	X	-	-	-	-	-	-	X	X	-	X	-	X
Sell a proportion or all animals in non-capital stock type with no feed allocation	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-
Draft mobs	-	-	-	-	-	-	X	-	X	-	X	-	X	-	-	-	-
Wean mobs	-	-	-	-	-	-	-	X	X	-	-	X	X	-	-	-	-
Wean all mobs	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Set draft fortnightly for all mobs	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-
Sell all non-capital stock	-	-	-	-	X	-	-	-	-	-	-	X	X	-	X	X	X
Reset and start again	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

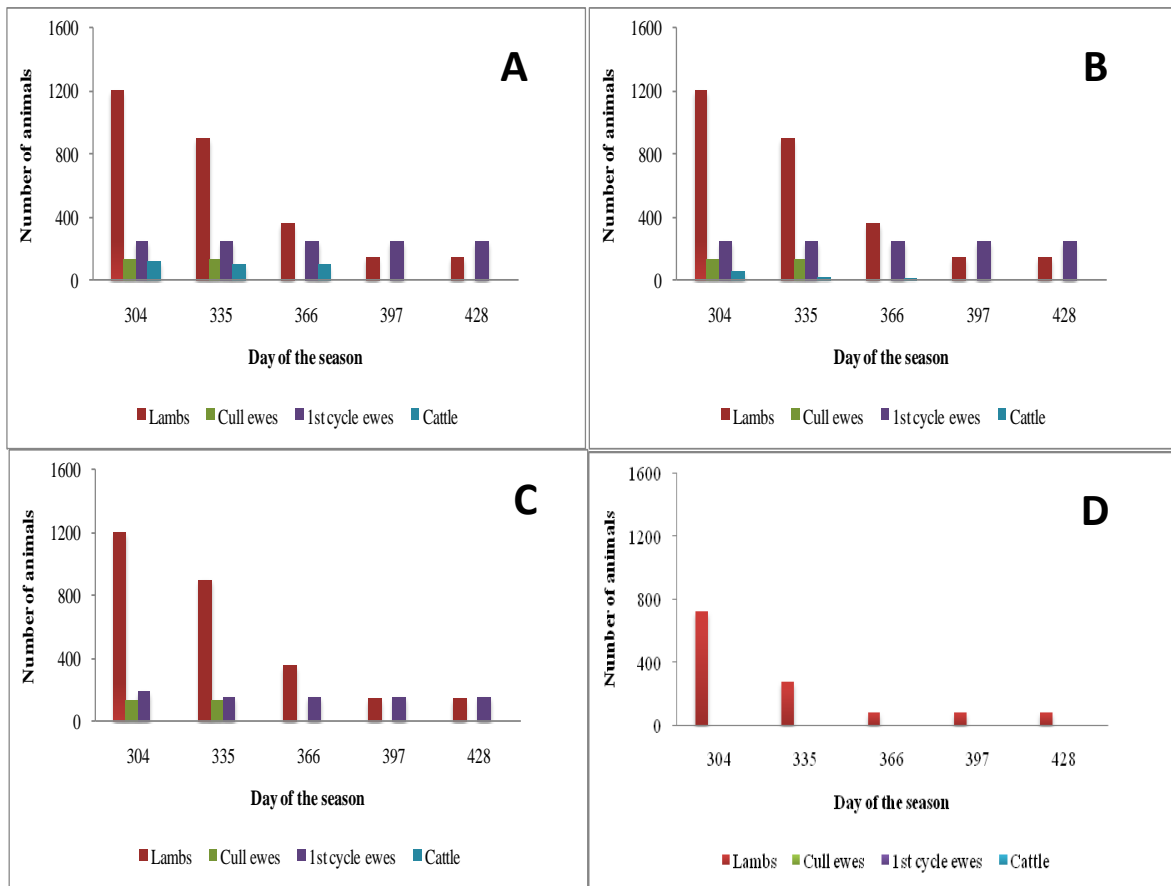
Where N=No, Y=yes, and X the corresponding marketing and/or destocking response

In scenarios where moisture level is above the corresponding target trigger levels of 10.0, 12.5 and 15.0%, tests for feed available for animals on hand are not implemented; rather the proportion of the lambs weighing greater than target weaning weight (WW) and the average lamb LW (ALW) are tested irrespective of the results of the current date test. If more than 10.0% of lambs are heavier than the target DW and the ALW is lower than the target WW, lambs are drafted. Where less than 10.0% of lambs are heavier than the target DW and the ALW of the lamb crop is higher than the target WW, lambs are weaned.

A delay occurs between the time a producer opts to sell stock and the actual killing space allocation. An average of between 7-10 days delay has been suggested as the time between killing space booking and allocation in late spring through summer for the Canterbury region of New Zealand (A.C. Bywater, pers com). However, the delay is dynamic ranging between 7 to 12 days.

### **6.3. Results**

Figure 6-6 presents results for the algorithm test for the hypothetical farm described above. When feed available was enough to feed the non-capital stock to the end of the season, all stock classes were retained on the farm and disposal was only as a result of sale following attainment of target drafting weight as shown in Figure 6-6A. This scenario simulates a farm situation where feed available is not limiting which means the destocking and marketing algorithm is able to respond to the planned marketing regime. For instance, all cattle were sold off at the end of the year which was the target marketing policy for the hypothetical farm.

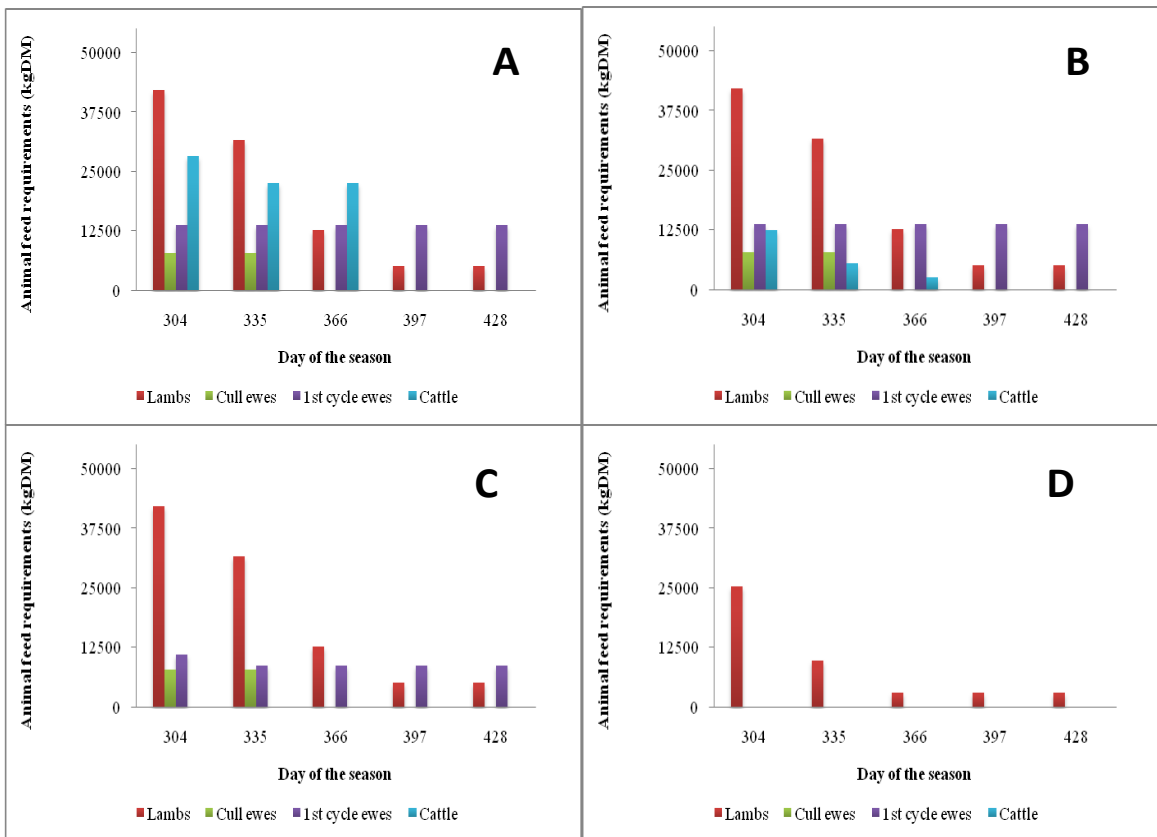


**Figure 6-6:** Animal number retained on farm when 100 (A), 75 (B), 50 (C) and 25% (D) of required feed is available for the non-capital stock

In all cases, cull ewes are sold off the farm after weaning as shown in Figures 6-6A-C while the 1<sup>st</sup> cycle ewes were retained on the farm in anticipation of a better than average pasture growth in the following season. In essence, culling could be carried out on the 1<sup>st</sup> cycle ewe mob with replacements being sourced from cull ewes deemed to be in better (re)production condition than animals in the 1<sup>st</sup> cycle ewe mob.

Figure 6-6D represents a situation where the farm cannot support all the lambs to finishing. It is notable that the height of the column representing the number of animals is shorter compared to the other three cases (Figure 6-6A, B and C).

Figure 6-7 shows the feed requirements corresponding to the number of animals presented in Figure 6-6. Generally, feed requirements follow the same pattern as the number of animals. The high number of lambs is reflected by high feed requirements especially towards the start of the season but as the season progresses and as more lambs are sold off, their requirements reduce and are overtaken by the cattle and 1<sup>st</sup> cycle ewes' requirements.



**Figure 6-7:** Total feed consumed by each stock category retained on farm when 100 (A), 75 (B), 50 (C) and 25% (D) of required feed is available for the non-capital stock

Unlike lambs and cattle, cull and 1<sup>st</sup> cycle ewe mobs were sold ‘all or none’ depending on the feed availability. For example, if a mob had a total of 100 ewes and the feed available is enough to maintain 80 ewes the mob was sold off entirely. Assuming lamb feed requirements have been satisfied, such a production circumstance led the algorithm to retain a certain number of cattle that can be fed using the feed saved from selling the entire ewe mob (i.e. feed for the 80 ewes). This algorithm capability ensures that no feed is unutilised irrespective of stock type prioritization.

## 6.4. Conclusions

Based on the destocking and marketing policies of the hypothetical farm, the algorithm reproduced well the projected and desired results. In general, the algorithm reported here can be used in any grazing system. In order to be used as a stand-alone decision aid, the farmer would be required to provide a stock type prioritization list, an estimate of the feed available at the time, and his or her estimate of the prospects of rainfall, presumably based on official current forecasts (from NIWA in the case of New Zealand).

The algorithm has been incorporated into the LincFarm model and an evaluation of the extended model carried out for all the new extensions before use in evaluating alternative risk management strategies. This is described in the next chapter.

## CHAPTER 7

### Evaluation of the Extended LincFarm Model

#### 7.1. Introduction

The original LincFarm model has been evaluated previously to identify and correct deficiencies in its predictive performance in simulating a grazing sheep system (Bywater *et al.*, 1999; Cacho *et al.*, 1995). However, new aspects (animal, pasture and management) have been introduced in the model in line with the objectives of this study. The main extensions to the Bywater *et al.* (1999) model include options for annual ryegrass and ‘switch’ pasture, a forage crop sub-model to simulate DM accumulation for crops such as kale, leaf turnip and rape, growing cattle, and a destocking and marketing algorithm necessary in simulating tactical responses to adverse climatic conditions tested in this study. Therefore, there is a need to carry out evaluation tests for these introduced aspects to correct any identifiable deficiency. Data against which an evaluation was carried out was obtained from SISST at Silverwood farm near Hororata, Canterbury, New Zealand (Bywater *et al.*, 2010).

#### 7.2. Silverwood Innovative Sheep Systems Trial (SISST)

The Silverwood Innovative Sheep Systems trial (SISST) was established in March 2007 with two farm units, an 87.8 ha grass-based unit and an 85.1 ha legume-based unit. The project was designed to address two main objectives. The first objective was to investigate and demonstrate key elements of high productivity sheep systems in dryland environments while the second was to push the boundaries of productivity and profitability under the prevailing production circumstances. Policies for operation of the two farm systems were determined in discussions between staff from Lincoln University and a farmer reference group from the dry east coast of the South Island (Bywater *et al.*, 2010).

Key elements of high productivity systems in dryland environments were seen as the use of high efficiency ewes with low bodyweight and high fecundity; maintenance of high pasture quality and utilisation leading to fast lamb growth rates and early drafting as well as good ewe condition prior to tugging and high scanning percentages; and flexibility to react to rapid changes in growing conditions (destocking) so as to minimise fluctuations in performance and profitability between years. The trigger to begin destocking (sale of cattle, weaning and sale of 1<sup>st</sup> cycle ewes, earlier weaning of main mob, and sale of store lambs) was the soil moisture level with the value set at 10% in the top 25 cm of soil (SML<sub>25</sub>). Conditions dried out around the first week of November in 2008-09 season prompting decision to begin destocking as rapidly as possible subject to availability of killing space. In the production year

2009-10, SML<sub>25</sub> did not reach the 10% trigger level at any time during the season and as a consequence, all weaning and sales were determined on weight alone.

The philosophy guiding the establishment of the grass based unit was to stock the unit for better than average growing conditions in order to maintain high pasture quality and utilisation, and to retreat from the high stocking rate when pastures dry out. Two year old cattle were included in the farm system to maintain low pasture residuals where necessary (clean up after ewes) and as a flexible stock class which, along with old ewes, could be sold as required. The old ewes were to be sold all counted (i.e. with lambs at foot) or after weaning. Lambs were to be weaned early if pastures dried out and the stocking rate was still high, with the older ewes being sold. Initially, it was targeted to contract between 70-75% of lambs as feeder lambs to finishing farms over November and December with all sale stock off the farm by the end of December. However in the event, feeder lamb contracts were not forthcoming and the policy changed to assessing feed supply at weaning with all lambs which could not be finished sold as stores as early as possible. The establishment SR was 14 SU ha<sup>-1</sup> against the district of 10 SU ha<sup>-1</sup> with an intention of increasing as the system became better developed.

The philosophy behind the legume unit was to maximise feed quality with high intake, high nutritive value species, mainly lucerne and annual and perennial clovers, with an objective of achieving high lamb growth rates and subsequent earlier drafting. High legume systems can experience feed deficit during winter/early spring and to address this, a proportion of the farm would remain in perennial grass pastures and a proportion would be in the 'switch' system (annual and perennial clovers, over-sown with annual ryegrass each autumn) to increase winter feed supply and provide high quality pastures in late spring/summer. Annual ryegrass has higher growth in the cool season (winter/early spring) than perennial grasses. The high growth provides high quality feed for early lambing ewes. Similarly, perennial clover has higher growth in late spring and in summer. Strict pasture control using grazing was not crucial to maintain pasture quality on the legume farm as it was on the grass farm system since legumes retain their quality longer than grass when left ungrazed. However, it remained important in terms of pasture utilisation. Cattle were replaced with '2 yr' ewes to act as a flexible stock class for sale where necessary. This implied more older ewes lambed early than on the grass unit, requiring more early growing pastures and hence the use of the annual ryegrass component of the switch pastures. The legume farm system was a higher cost system than the grass but was expected to compensate this with fast lamb growth rates and generally better persistence into dry conditions translating to more

lambs being finished thus reducing the number sold on feeder contract or as store.

### **7.2.1. Grass Farm System**

The grass based unit was divided into 16 paddocks using semi-permanent electric fencing. Temporary electric fence was used to rotate animals within paddocks. One paddock was in lucerne, two paddocks were put through a renewal sequence each year and the remaining paddocks were in a variety of different grass: clover mixes. The renewal sequence included optionally over-drilling with annual ryegrass in February/March for early growth the next season, cultivation and sowing into kale in November with one paddock sown into leaf turnip under-sown with permanent pasture in October following grazing of the kale the following winter, and the other sown into barley for silage and then into permanent pasture in February/March.

The farm was stocked with 858 mixed age ewes of mixed breeds, but mainly Coopworths from the Ashley Dene breeding flock and 55 18-months old cattle. This represents a stocking rate of approximately 14.0 SU ha<sup>-1</sup> compared with a district average of around 9.5-10.0 SU.

Replacement 2-th ewes were purchased prior to mating at around day 40 (February, 8) and store cattle were bought in early May (day 125 – 135). All stock were wintered on kale with balage or silage from the beginning of June until approximately a week before lambing with the cattle held on kale until the end of September or when pasture mass in the sheep paddocks reached 1500 kg ha<sup>-1</sup> any time after 15<sup>th</sup> September. They were spread out over all paddocks after the end of September if no paddock was greater than 1500 kg ha<sup>-1</sup>. If the pasture mass in the paddock in which cattle were grazing reached 1200 kg ha<sup>-1</sup> they were moved to the next highest paddock in the farm. The cattle were sold based on feed budget any time after October.

A total of 208 old ewes were mated at around day 79 (March, 20) for lambing from day 232 (August, 20). They were lambed onto paddocks with the highest mass and moved as soon as the lucerne was ready for grazing. This was sometimes around day 289 (mid-October). The mixed age ewe mob was mated at around day 96 (April, 6) for lambing from day 249 (September 6). The ewes were mated at 65.0 kilograms with a ram to ewes' ratio of 1:100. It was assumed that 50% of the ewes gave birth to twins with the remainder lambing singles. The ewes were scanned at 90 days from the start of mating.

Weaning was determined on the basis of a target average weaning weight of 25.0 kg, depending on feed conditions. Drafting of lambs started as soon as reasonable numbers reached a drafting weight of 32.0 kg rising to 34.0 kg at weaning. Any lambs ready for

drafting at weaning and cull ewes were sold. An assessment was made on the number of lambs which could be finished on the feed available; any excess lambs were sold from the lightest lambs as stores and remaining lambs break-fed on lucerne or leaf turnip.

### **7.2.2. Legume Farm System**

The legume based unit was divided into 16 paddocks using semi-permanent electric fencing. Temporary electric fence was used to rotate animals within paddocks. Out of the 16 paddocks on the unit, 5 were put into perennial grass pasture. A further 5 paddocks were put into a 'switch' pasture system, which is a mix of annual and perennial clovers into which annual ryegrass is drilled each autumn. The farm was stocked with 832 mixed age ewes mostly Coopworths from the Ashley Dene breeding flock and 242 old ewes retained from cull-for-age ewes from the previous season. This latter group was considered as a flexibility option. A total of 281 old ewes were mated at around day 72 (March, 13) for lambing from day 218 (August, 6) while the main mob of mixed age ewes was mated at around day 96 (April, 6) for lambing from day 249 (September, 6). Rams were a mix of breeds, but primarily Dorset Down.

The legume farm's management was similar to the grass farm system except in the following aspects: ewes were lambed onto grass and switch pastures; they were spread out onto lucerne as it became available from day 288 (mid-October); ewes from the paddocks destined for renewal were shifted onto lucerne first with lambs moved onto lucerne progressively after weaning. Detailed records on the management of the SISST project are presented in Bywater *et al.* (2010). Performance records for the SISST project from which data were used in this evaluation are available from Bywater *et al.* (2010) and field day reports and the monthly newsletters posted on the Silverwood farm website<sup>2</sup>.

### **7.3. Simulation Runs**

This section describes the set up of the model farm. Two simulation runs were made with each representing either the grass or the legume farm system. The farm size for each was 100 ha divided into 16 equal paddocks. Each of the farm systems was stocked at 14 SU ha<sup>-1</sup>. Since the objective of the report presented in this section is to evaluate the performance of the extended LincFarm model performance using data from the SISST project, values corresponding to the model input variables were adopted from SISST project reports. For

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<sup>2</sup>See <http://www.lincoln.ac.nz/SF/Silverwood-Farm/>

instance, two mobs of cattle were set to be bought into the farm. The first mob of 44 steers was bought into the model farm on day 152 (May 8) and the second mob on day 157 (May 13) of the year. This corresponds to the day cattle were bought into the SISST grass based farm unit. Therefore, the information describing the operation of the grass and legume systems (under section 7.2) was taken to satisfactorily describe values and conditions considered in setting up the respective model farms. Table 7-1 gives a summary of the model farm variables. As shown, many of the management activities were similar between the two systems. However, the systems differed in that the legume farm system had a switch pasture system which was not included in the grass farm system. Another important difference was the use of a 1<sup>st</sup> cycle ewe policy as a flexibility option to managing climatic variability on the legume farm system compared to use of cattle on the grass based farm system. Although both farm systems had an area under lucerne, only 1 paddock was available on the grass farm compared to 4 under the legume system.

Sale lambs were first drafted at 32.0 kg LW and at 34.0 kg for the subsequent drafts at fortnightly intervals between November and February with a target of finishing as many lambs as possible by the end of February at which point all remaining lambs were sold off store. However, at weaning an assessment in relation to the feed situation (current and/or projected) was carried out to determine how many lambs could be finished with the bottom end lambs being sold store. Generally, animals were split into mobs and subjected to different grazing rules depending on pasture availability, time of the year and relative priorities of different classes of stock.

**Table 7.1: Model farm description and variables**

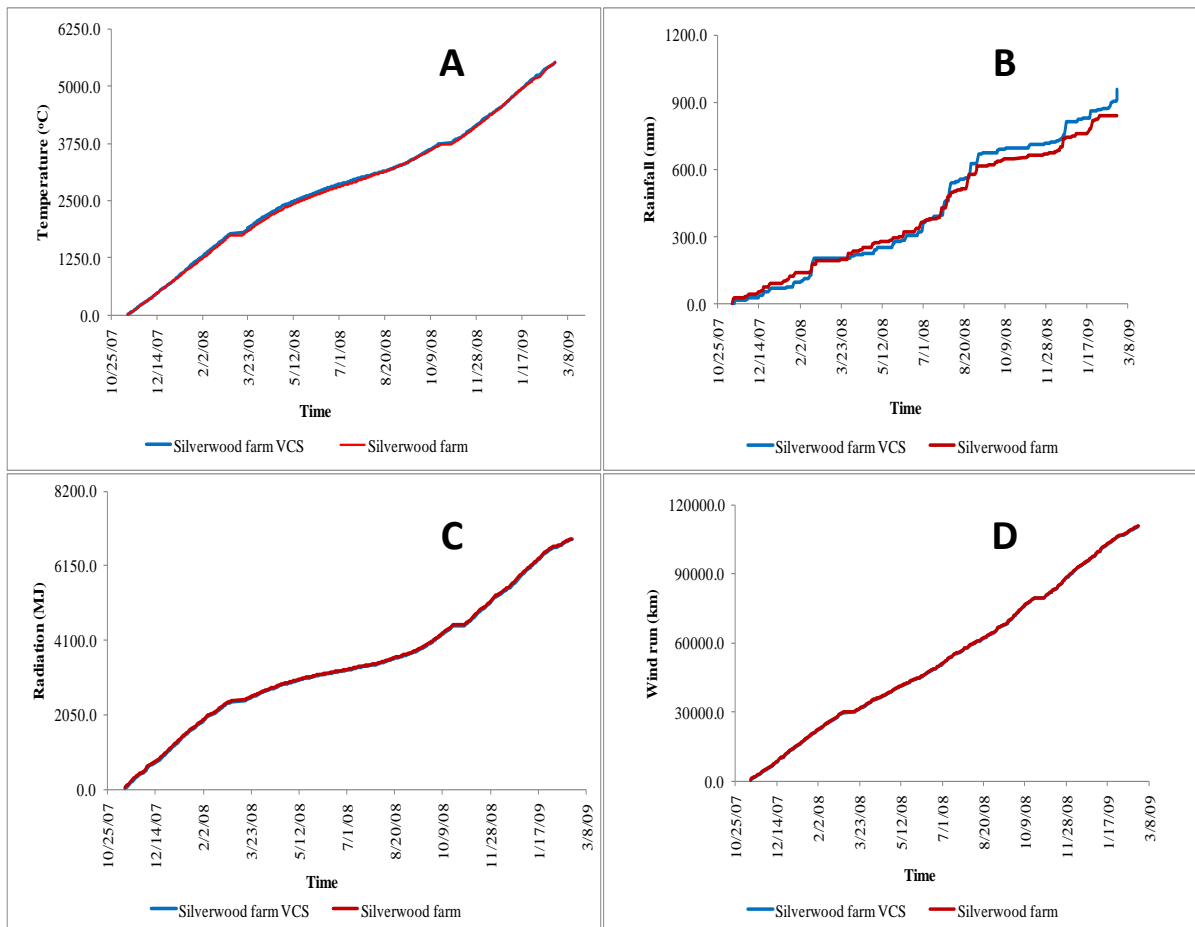
Farm Description <sup>1</sup>		
Farm Type	Grass based system	Legume based system
Physical Description	100 ha divided into 16 equal paddocks	100 ha divided into 16 equal paddocks
Pastures	Annual and perennial ryegrass, annual and perennial clovers, tall fescue, cocksfoot, lucerne, kale, barley, and leaf turnip	Annual and perennial ryegrass, annual and perennial clovers, lucerne, kale, barley, and rape
Stocking rate (SU ha <sup>-1</sup> )	14	14
Stock Numbers		
Breeding ewes	858	1080
Mixed age ewes	678	800
Old ewes	180	280
Rams	9	11
Cattle	55	0
Ram to ewes ratio	1:72	1:72
Stock management (day):		
Flushing Old ewe mob	35	35
Mixed age ewes mob	59	59
Tupping; Old ewes mob	72	72
Mixed age ewes mob	96	96
Weaning; Old ewes mob	316	316
Mixed age ewes mob	334	334
Shearing <sup>2</sup>	120, 243 and 360	120, 243 and 360
Vaccination; Ewes	196	196
Lambs		
Drenching; Ewes	230	230
Lambs	316	316
Dipping	196	196
Culling; Ewes	335	335
Rams	335	335
Replacements		
Ewes (join ewe mob)	335	335
Rams (purchase)	14	14
Lamb Sales	First draft was done at 32 kg LW and then at 34 kg LW at fortnightly intervals between November and end of February. Remaining lambs were sold store at the end of February; Cattle sold at weight anytime from October	First draft was done at 32 kg LW and then at 34 kg LW at fortnightly intervals between November and end of February. Remaining lambs were sold store at the end of February
Grazing management		
Ewes; Flushing	23	23
Tupping	65	65
Winter	90	90
Lambing	214	193
Lactation	296	296
Summer	334	334
Rams; All year except when tupping	Set stocked on rams block	Set stocked on rams block
Lambs; Post-weaning	Shuffle fed best cover	Shuffle fed best cover

<sup>1</sup>Time of the season is in Julian date; <sup>2</sup>Shearing occurred every 8 months in April, August and December

In order to run the extended LincFarm model climate data is required. The following section gives an analysis of the climate data used in this evaluation.

### 7.3.1 Climate Data

While there was a weather station installed at Silverwood farm, intermittent problems with the electronics in the station meant that there were a number of gaps in the data over the three years of the trial. Weather data used in running the simulation were therefore obtained from the National Institute of Atmospheric Research of New Zealand (NIWA) Virtual Climate Station Network (VCSN). The VCSN data are based on spatial interpolation of the data from observation sites onto a regular grid that is approximately 5 x 5 km resolution covering the whole of New Zealand (Tait A. *et al*, 2006). Figure 7-1 shows a comparison of weather data obtained from the VCS station and the data that are available from the Silverwood farm station where the SISST project was carried out. In all cases, the values for different weather variables required in running the simulation compared well between those obtained from the VCSN based Weather Station and the ones measured at Silverwood farm for the period 2007-2010. Use of data for weather variables of interest from the Silverwood farm VCSN based Weather Station was thus considered acceptable for the purposes of simulating pasture growth at Silverwood in this study.

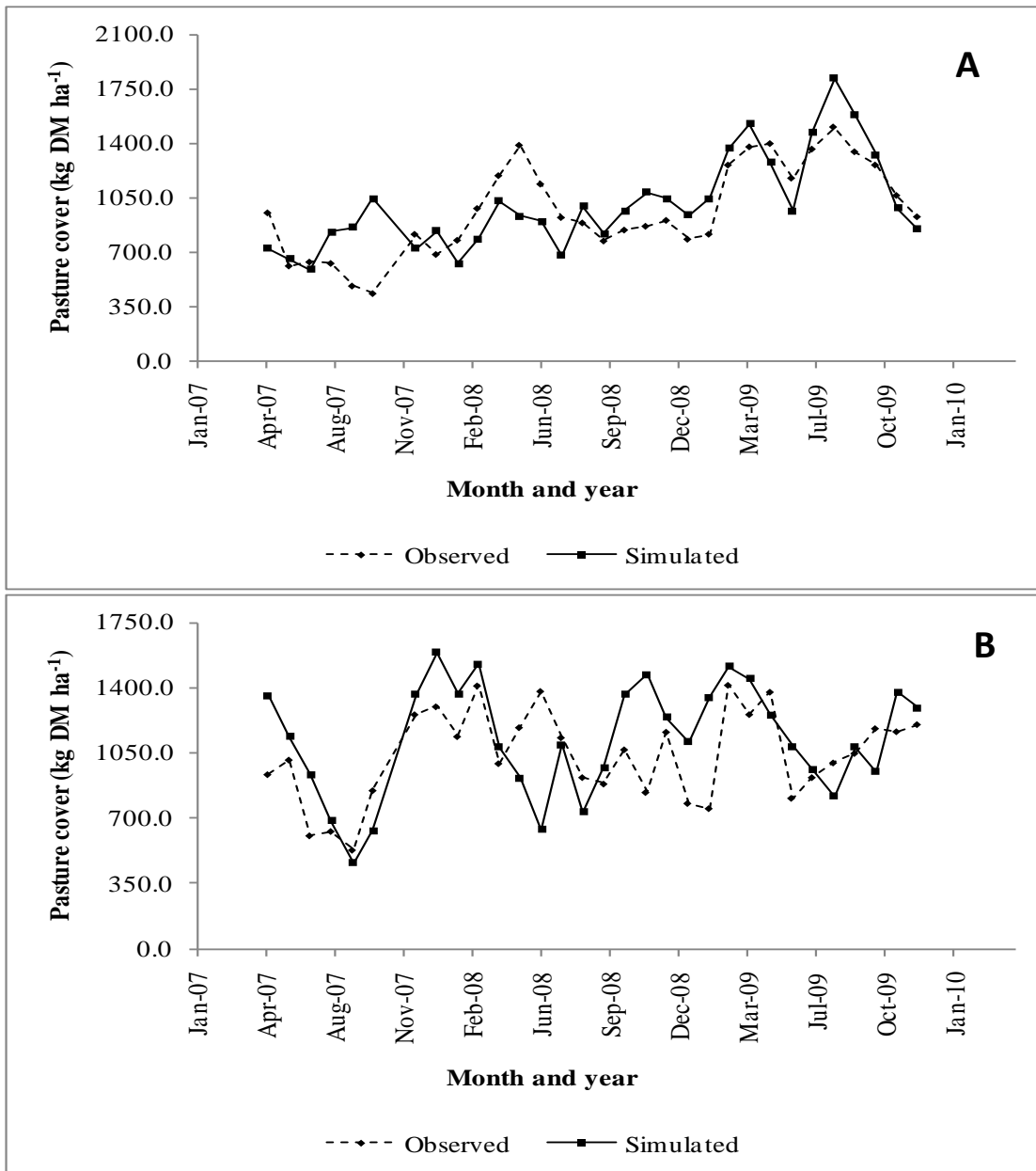


**Figure 7-1:** A comparison of weather data obtained from Silverwood farm VCS and three years data obtained from the Silverwood farm for temperature (A), rainfall (B), radiation (C) and wind run (D)

Running the extended LincFarm model for a 5 years period and extracting data corresponding to available data from the SISST project allowed an evaluation of the model performance. Only results for the newly introduced aspects are presented in the results section below as most other aspects have been adequately evaluated in previous research (Finlayson *et al.* 1995; Cacho *et al.* 1995 and 1999; Bywater *et al.*, 1999) utilising the original LincFarm model.

#### **7.4. Results**

Results for the farm pasture cover for the grass and legume farm units are shown in Figures 7-2A and B respectively. The simulated and observed data values for the grass farm unit differed more in the first season of the trial compared to the second and third. However, in the legume farm (Figure 7-2B), the difference was greater in the production season 2008/09 compared to seasons 2007/08 and 2009/10. Overall, the model tended to overestimate the legume farm cover. This can be explained by the poor performance of lucerne on the legume unit which was noted as one of the reasons for the lower gross margin on this unit compared to the grass unit, probably due to the age of the lucerne (Bywater *et al.*, 2010).



**Figure 7-2:** Comparison of simulated pasture covers for the grass- (A) and legume-based (B) systems compared with data from Silverwood grass and legume trial units for the production period 2007/08 to 2009/10

Table 7-2 presents summary validation statistics for the mechanistic pasture model against pasture cover data obtained from Bywater *et al.* (2010) for grass- and legume-based farm units. MSD (RMSD<sup>2</sup>) indicates the overall deviation of the model output from the measurement while its components represent different aspects of the deviation. RMSD which represents the mean distance between the model and the data was 48.03 and 102.66 kg DM ha<sup>-1</sup> for the grass- and legume-based farms.

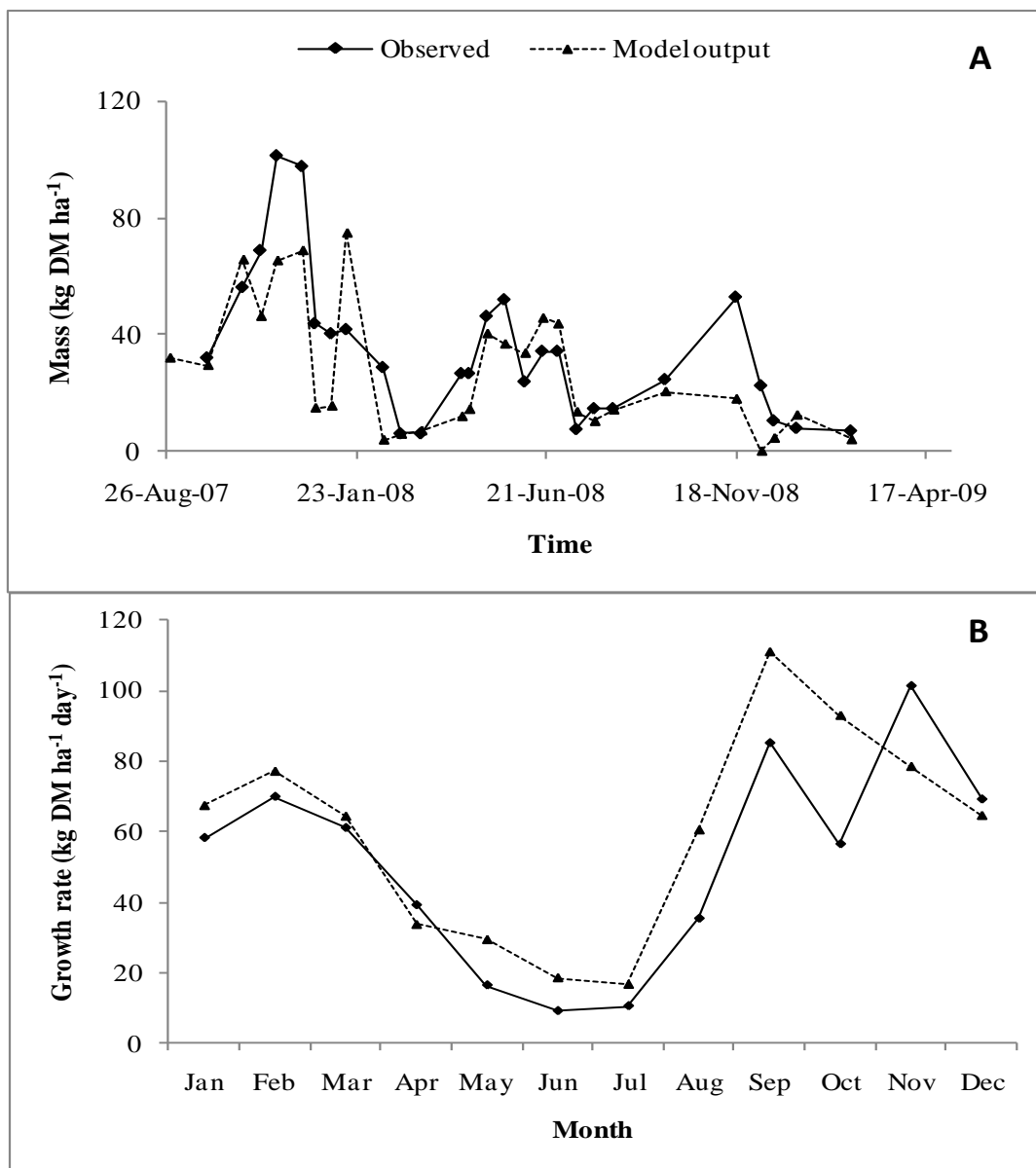
**Table 7.2:** Summary validation statistics for the pasture model against pasture cover data for grass- and legume-based trial farm units obtained from Bywater *et al.* (2010)

Criterion <sup>1</sup>	System	
	Grass-based	Legume-based
MSD	2333.20	10539.74
RMSD	48.03	102.66
SB	494.76	873.28
SD <sub>s</sub>	163.88	178.16
SD <sub>m</sub>	198.23	257.76
LCS	658.52	3330.30
SDSD	1179.92	6336.16
r	0.89	0.63

<sup>1</sup>See section 2.9 for description of the evaluation criteria

The standard deviation of the measurements (SD<sub>m</sub>) resulted in higher values implying that much of the difference between model simulated pasture cover values and the data is due to the measurement errors. This is further shown by the large value of SDSD both for the grass and legume units. The high values of *r* especially for the grass-based unit shows the model is capable of simulating pasture cover accurately. The high MSD value for the legume-based farm unit indicate the overall deviation is not entirely dependent on the correlation ( $r = 0.63$ ), but is mainly due to the expected high variability between measurement (Bywater *et al.*, 2010; poor performance from old lucerne pasture) and simulation.

Switch pasture and lucerne growth rates on the legume farm unit are presented in Figure 7-3A and B respectively. The switch pasture system involves alternating white and red clover and annual ryegrass within the same paddock. The annual ryegrass has higher growth in early spring especially in cool seasons which provides high quality feed for early lambing ewes. Lambing ewes earlier has implications for managing climatic variability in this study. No clear pattern was observable between the observed data and model output. However, the model estimated growth rate tended to be lower than the observed in most periods (figure 7-3A). Figure 7-3B shows growth rate comparison between simulated and observed data for lucerne. In almost all cases, the model output values for lucerne growth rate was higher.



**Figure 7-3:** Comparison of simulated growth rate for switch pasture (A) and lucerne (B) with observed data from Silverwood grass and legume farm units

An important observation is that the lucerne paddocks in the SISST project were thought to be approximately 7 to 9 years old and performed very poorly according to the project management report (Bywater *et al.*, 2010). This would be expected to affect growth and partly explains the difference between the model output and field data.

Table 7-3 presents summary validation statistics for the mechanistic pasture model against switch pasture and lucerne growth rate data obtained from the Silverwood legume-based trial unit (Bywater *et al.*, 2010).

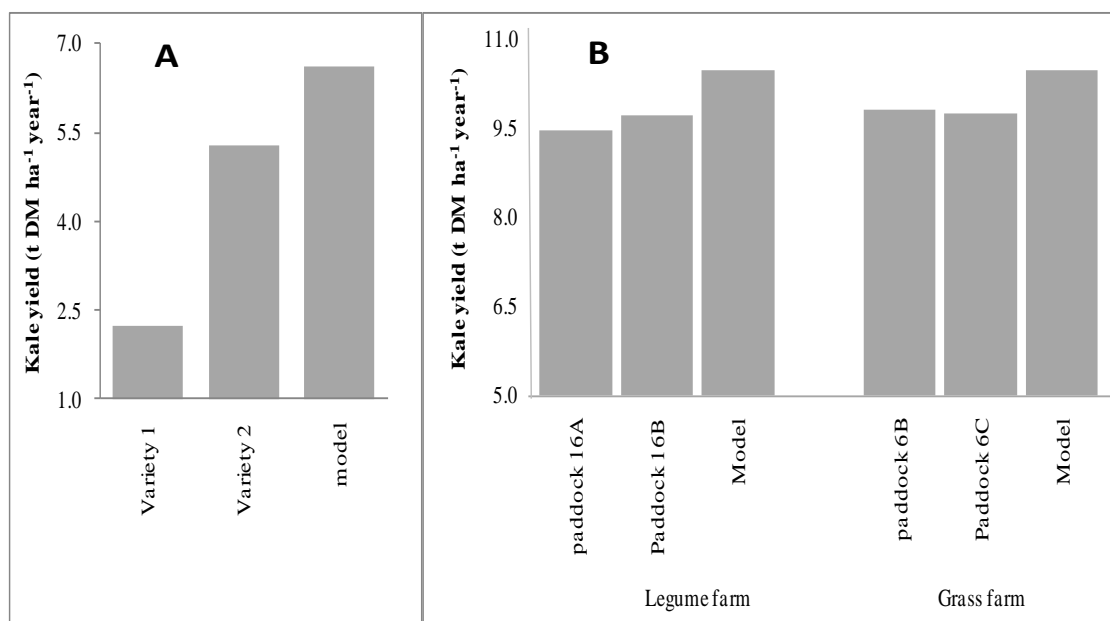
**Table 7.3:** Summary validation statistics for the pasture model against switch pasture and lucerne pasture growth rate data obtained from Silverwood legume-based trial unit (Bywater *et al.*, 2010)

Criterion <sup>1</sup>	Pasture type	
	switch	lucerne
MSD	18.13	21.64
RMSD	4.26	2.76
SB	10.15	15.63
SDSD	5.51	3.94
LCS	2.47	2.07
r	0.78	0.71

<sup>1</sup>See Section 2.9 for description of the evaluation criteria

The respective mean modelled switch pasture and lucerne growth rates were 3.19 and 3.95 (obtained from respective square root of SB) kg DM ha<sup>-1</sup> day<sup>-1</sup> greater than the mean for data. SDSD and LCS are small for both switch pasture and lucerne. This results in a small MSD (see equation 2:17) implying that there is small variability between measured and modelled switch pasture and lucerne growth rates.

Data were available for kale yields for the production periods 2008/09 and 2009/10. In the first year, yield data were presented based on the kale variety planted while in the second year, yield was reported for specific paddocks on the grass and legume units. Figure 7-6 presents the comparison of the modelled kale yields and the data. Generally, the model tended to overestimate kale yield for the two production periods. However, the difference was highest for kale variety 1 for the period 2008/09. This observation was identified in Bywater *et al.* (2010), who noted that the low values for this period were mainly due to kale cultivar planted coupled by late sowing. Following that observation, a corrective measure was applied resulting in the high yields obtained in the production period 2009/10. Model estimates and data for the period 2009/10 are acceptably comparable for the purposes of this study.



**Figure 7-4:** Comparison of simulated kale yield with observed data from Silverwood trial farm units for production period 2008/09 (A) and 2009/10 (B)

Data on cattle sale weight were available for the grass system unit and were used to compare with model cattle liveweight values at corresponding dates and results are shown in Table 7-4. A difference ranging between +3.0 and -3.0% existed with the model tending to slightly overestimate cattle LW earlier in the season 2006/07. However, the differences could be attributable to the initialisation of cattle LW in the model. The observed sale weight is an average of a number of cattle sold on a particular date. The initial LW value for the model corresponded to the average LW at which the cattle were bought onto the grass unit.

**Table 7.4:** Comparison of observed cattle sale and corresponding model LW on the grass system unit

Date	Cattle sale weight	Model value	%difference
23/12/07	482	479	-0.62
08/09/08	461	475	+2.95
24/11/08	536	521	-2.87

Further tests were carried out to evaluate the working of the incorporated destocking algorithm. Notable in the tests was the fact that the algorithm introduced the aspect of a dynamic management calendar and it was important that an action resulting from implementation of the algorithm was captured in relation to the fixed policy management calendar and the overall working of the original LincFarm model so as to ensure the algorithm implementation did not introduce unintended errors.

The tests were based on sample decision rules presented in Table 6-1. Variables were deliberately changed and output from the incorporated destocking algorithm obtained and compared with expected. For instance, if tailing was set not to have occurred, it would be

expected that the algorithm would reset and a retest of tailing would continue occurring until it was carried out before the destocking system would be actioned. Assuming tailing had occurred, the algorithm would proceed to carry out the next test which is to evaluate the current day and if it is less than 31<sup>st</sup> October then the algorithm proceeds to carry out a soil moisture level test. If this is below the target level, destocking actions should be implemented (sell cattle in grass-based system, wean 1<sup>st</sup> cycle or main mob ewes, etc.). However, if the test date is greater than 31<sup>st</sup> October then the algorithm proceeds to test the proportion of lambs in a mob that are above target drafting weight (DW) which is followed by a test for the percentage lambs LW which is greater than DW. Assuming at least 10.0% of the lambs are greater than the target DW, the lamb mob is drafted. The algorithm is then expected to proceed to test the proportion of lambs whose weight is greater than the target weaning weight (WW).

In all cases the algorithm followed the expected path and was considered to satisfactorily address the objectives of simulating tactical responses evaluated in this study.

## **7.2. Conclusion on the Evaluation of Extended LincFarm Model**

The main purpose of this comparison between model output and observed data is to give a general view of the suitability of the model to achieve its intended purpose rather than to establish the similarity between individual values. Given that the LincFarm model has been extensively evaluated in the past, and based on the results obtained from evaluating the extended LincFarm model reported above, the performance of the extensions within the original model appear satisfactory. Therefore, it is concluded that the extended LincFarm model is capable of evaluating alternative risk strategies for managing climatic variability in high performance sheep systems as set out in this study.

## CHAPTER 8

### Evaluation of Alternative Risk Management Strategies

#### 8.0. Experimental Protocol

The extended LincFarm model was used in evaluating alternative risk management strategies for a hypothetical farm based on the grass unit in the SISST (Bywater *et al.*, 2010). The farm consists of a 100-ha property in the Canterbury Plains of New Zealand divided into 16 equal-size paddocks each measuring 6.25 hectares. Thirteen paddocks are sown in perennial ryegrass:clover mixed pasture, two paddocks into forage crop (kale) and one paddock into lucerne. One of the two kale paddocks is sown in barley for making silage after the kale is grazed while the remaining paddock is put into leaf turnip under-sown with pasture.

The farm is stocked at 10 SU ha<sup>-1</sup> with Coopworths sheep representative of the Ashley Dene breeding flock. Replacement ewes are purchased outside the farm with the number depending on the strategy being tested (alternative management strategies tested differ in the stocking rate). Seven different strategies are evaluated, each including different combinations of pasture types and stock classes representing different management flexibility options. Each strategy is evaluated at 10, 12, 14 and 16 SU ha<sup>-1</sup>, first without and then with the application of short-term tactical responses to climate conditions (the destocking and marketing algorithm). Mature ewes are counted as 1.1 SU, rams as 1.0 SU and 18-month-old cattle as 5 SU. The stocking rate was measured on 1 July, when all lambs are off the farm. Depending on the lambing percentage, the actual stocking rate will be greater during other times of the year.

Generally, lambs are drenched at weaning and subsequently on faecal egg count (FEC) status. Sale lambs are drafted at 37.0 kg LW at fortnightly intervals between November and February with a target of finishing as many lambs as possible by the end of February at which point all sale lambs are sold off store. During the production period, animals are split into mobs and subjected to different grazing rules depending on pasture availability, time of the year and relative priorities of different classes of stock.

Rotational grazing is simulated through a set of grazing rules; other management events are simulated through an event calendar. Any feed that is not utilised in the year is conserved and offered to the flock during the following winter, and during other times of feed constraints. Details on the grazing rules and their implementation are presented in Finlayson *et al.* (1995).

Climate data is required in running the LincFarm model while price data is used in

estimating gross margins of alternative strategies. The following section describes the climate and price data including their relationships as used in this study.

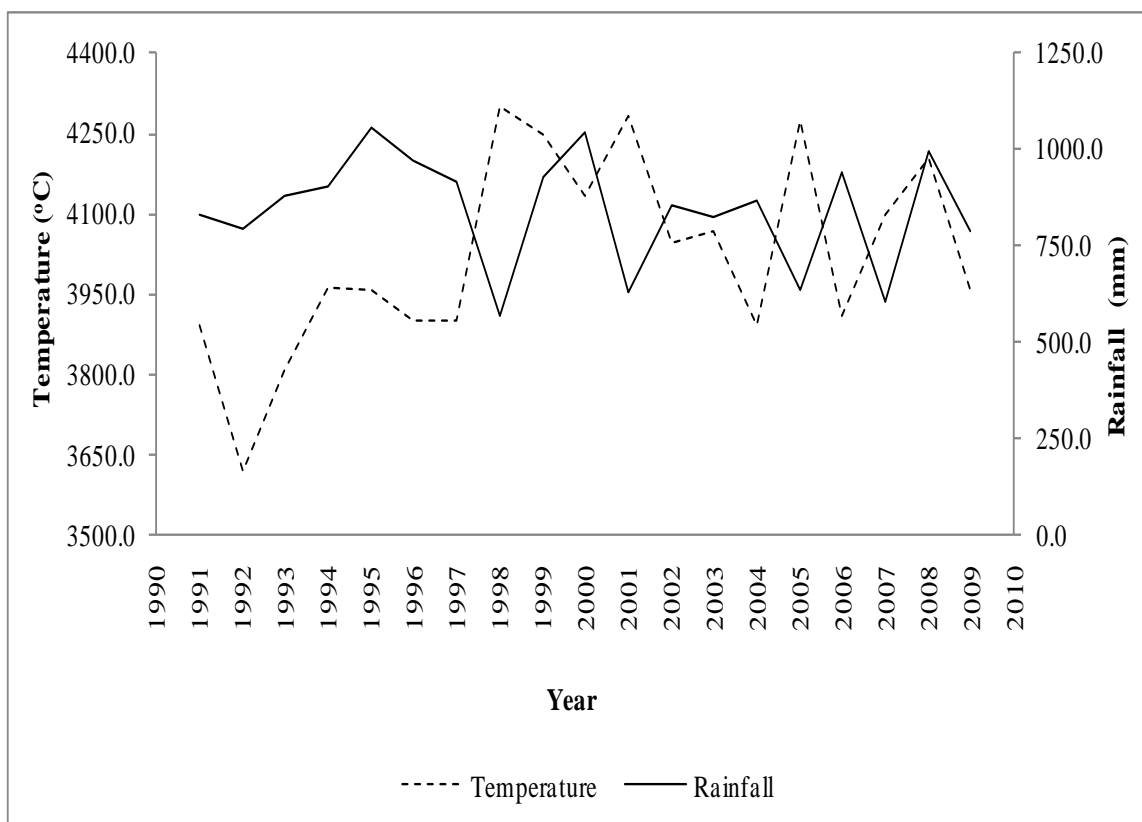
## **8.1. Climate and Price Data Analysis**

As noted in the previous chapter, climate data used in this study was obtained from NIWA Virtual Climate Station Network (VCSN) while price data was obtained from weekly meat prices for the months of October, November, December, January and February, (months relevant to sale time in this study) from the financial budget manuals published by Lincoln University (Financial Budget Manuals for the period 1994 to 2010). The budget manuals are now produced biannually and give comprehensive data for various agricultural activities carried out in New Zealand.

### **8.1.1. Silverwood Farm VCS Rainfall and Temperature Data**

Climate is an important driving factor in determining pasture ecosystem processes and principally controls the biomass availability and distribution (Bai *et al.*, 2004; Barrett *et al.*, 2002). In New Zealand, seasonality in herbage production primarily drives lamb production (Morris *et al.*, 1993). The variable seasonal pattern of pasture production is mainly influenced by temperature and rainfall (Baars and Waller, 1979). Climate variability has a major impact on the productivity and profitability of livestock farms (Diaz-Solis *et al.*, 2006).

Figure 8-1 shows 19 years of the annual average values of rainfall and temperature for a VCSN located at latitude -43.559962 and longitude 171.84911 corresponding to Silverwood farm for the period 1991-2009. Year 1998 received the least amount of annual rainfall at 567.10 mm while the highest annual total rainfall was recorded in the year 1995 and was approximately 1055.90 mm. Year 1998 not only received the least total amount of rainfall, it is also the year that recorded the highest total annual temperature (obtained by summing up average daily temperature readings) at 4298.60 °C.

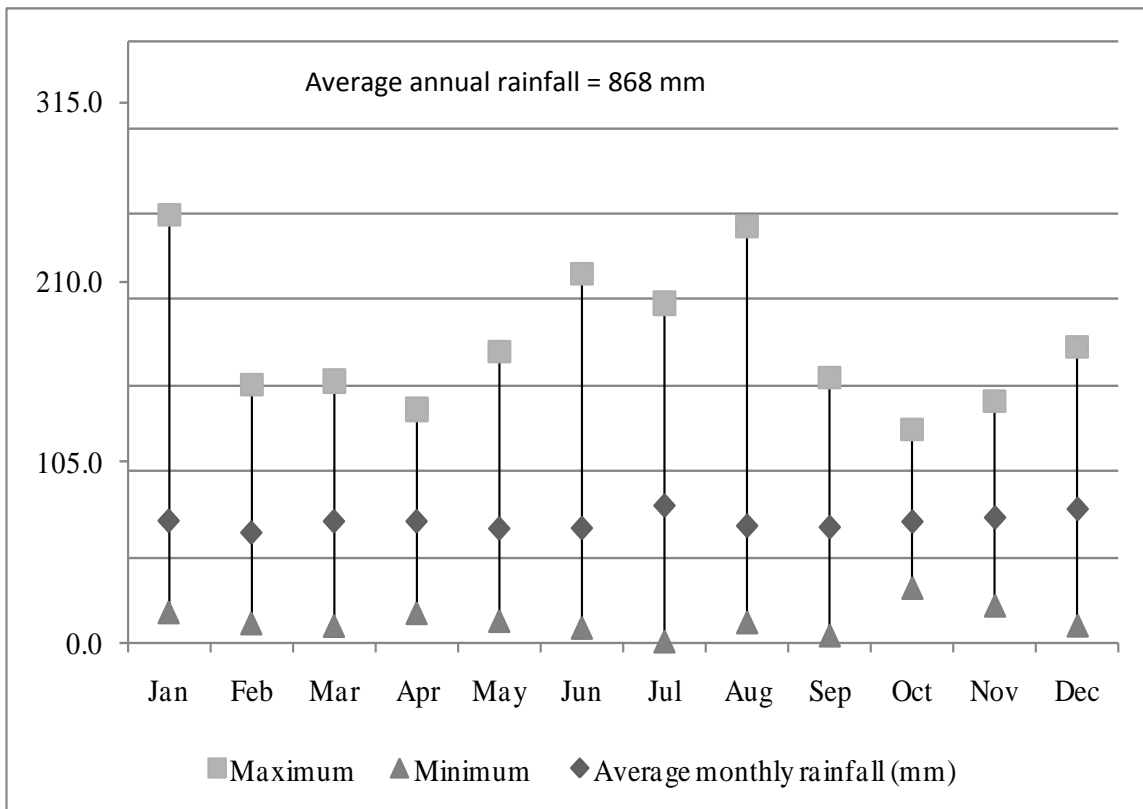


**Figure 8-1:** Total annual rainfall and temperature at Silverwood VCS for the period 1991-2009

Low rainfall and accompanying high temperatures would be expected to result in least pasture growth and a subsequent reduction in income in pastoral-based farm enterprises. In extreme cases, such scenarios result in drought conditions such as, the 1988-1989 drought reported by Nield (1990). The drought was estimated to have cost the east coast of the North Island \$240 million in reduced income and the total region \$1000 million (Nield, 1990).

It is evident from the data shown in Figure 8-1 that the area from which the data was obtained has a climate that varies significantly amongst years. It is this variability that this study intends to address by evaluating alternative potential management policies that can reduce its impact during bad pasture-growing seasons or take advantage of better than average pasture growing periods.

Radcliffe and Bars (1987) identified rainfall as the main climatic factor constraining pasture production in New Zealand, with spring and summer rainfall accounting for 60.0% of the variation in pasture production. Figure 8-2 shows the variability in the monthly average rainfall for the Silverwood farm VCS for the period 1991-2009.

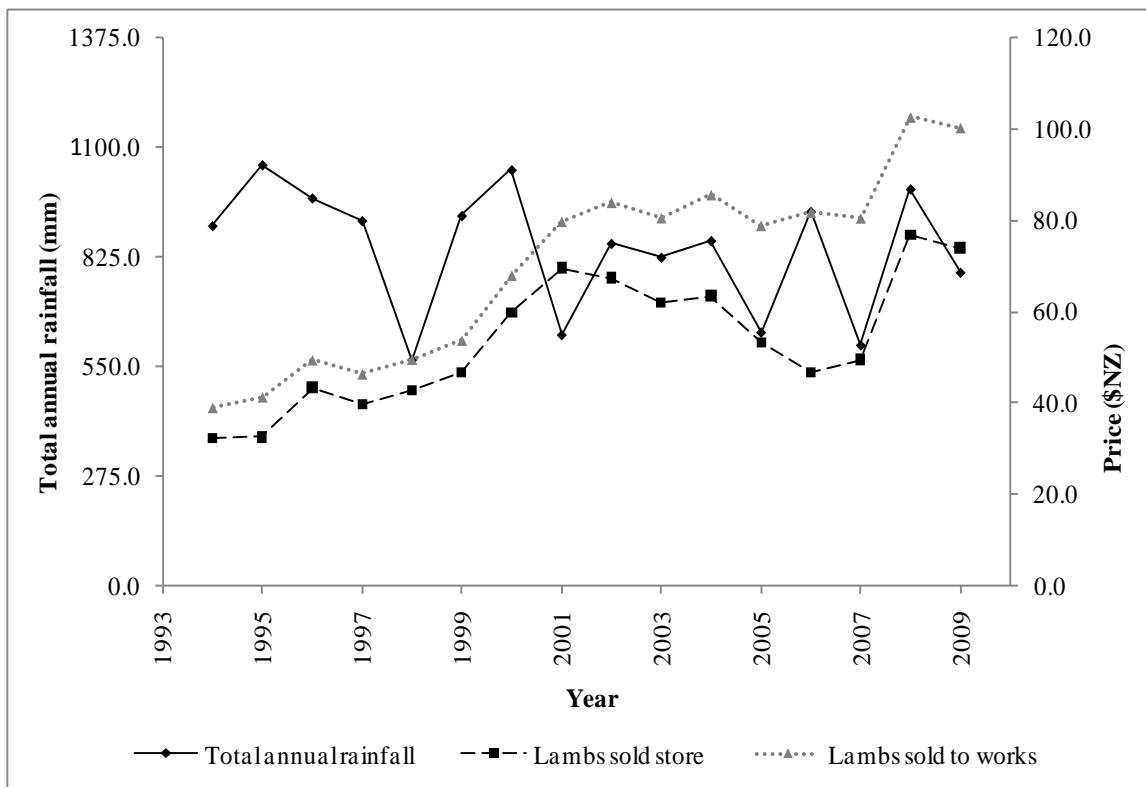


**Figure 8-2:** Variability in monthly average rainfall at Silverwood farm VCS for the period 1991-2009

Somewhat surprisingly, the area receives an average rainfall of 60-80 mm every month, but viewing the averaged monthly rainfall data without considering within month variability conceals a wide range of extremes as shown by the high variability for most of the months presented in Figure 8-2. For example, July received rainfall ranging from 1.10 mm to 197.9 mm over the 19 years of data considered in this study. There is considerably more variation in average monthly rainfall between May and September and again in December and January than in other months of the year. This largely confirms the observation by Radcliffe and Bars (1987) that variation in spring and summer rainfall accounts for the highest variation in pasture production due to precipitation received.

## 8.2. Relationship between Lamb Price and Rainfall Changes

Figure 8-3 shows a comparison of the total annual rainfall and lamb prices for the month of November for the period 1994-2009. The trends for lambs sold store and those sold to the works differ and vary differently in relation to total annual rainfall.



**Figure 8-3:** A comparison between lambs price and total annual rainfall for the period 1994-2009

There was continued increase in the price of lambs sold to the works between 1994 and 2001 followed by a period of relatively flat prices to 2007 and then a significant increase in 2008-09. Generally, prices for lambs sold to the works appear unresponsive to rainfall variability. This was expected as this segment of pastoral agricultural would be expected to be affected more by the international market trends compared to local weather situation. Conversely, price for lambs sold store is much more responsive to rainfall variation. This is an indication that more animals are available for sale when conditions dry out resulting in an oversupply which tends to lead to price reduction. This is expected and forms an important aspect being investigated in this study; when and how many animals does the producer sell in response to climate variation not forgetting that there is always a possibility that a substantial amount of rainfall can be received later in the season (example December/January) to support pasture growth enough to sustain lambs until they are finished.

Market variability constitutes the market risk as it reflects changes in input costs and output prices in a production system and has been identified as an important source of risk (MAFF, 2001). This market risk needs to be considered in making decisions to respond to potential threats or opportunities introduced by climatic variability in dryland sheep systems. A simple sensitivity analysis of gross margin to changes in prices was evaluated in this study. The analysis was carried out by applying different set of prices to the simulation results. The

prices were varied at three levels by multiplying the current market price by a factor of 0.875, 1.125 and 1.25, assuming a 12.5% price reduction, and 12.5 and 25.0% increases respectively. Results for strategy 4 with and without considering tactical response were used for this simple sensitivity analysis. However, it is important to note that the simple price sensitivity analysis presented here was meant to highlight the importance of considering market risk in risk management strategies. Detailed analysis of market risk was not a focus in this study. In fact one of the future research recommendations identified in this study is the inclusion of prices in the risk analysis framework.

### 8.3. Risk Management Strategies

The following are the seven strategies containing different flexibility options considered as having the potential to reduce the negative impact of climatic variability on productivity and profitability in high performance dryland sheep systems: They were chosen because they were thought to hold productivity potential based on experience gained in setting and running the SISST grass and legume systems which was done in consultation with a farmer reference group in the study area (see section 2.5).

1. The hypothetical farm described earlier stocked with sheep at 10, 12, 14 and 16 SU ha<sup>-1</sup>.
2. The hypothetical farm as in strategy 1 above but with 25.0% of the ewes replaced with equivalent cattle stock units; bought May, sold at weight from October, or when pastures dry out. The cattle are rotated through ewe mobs to retain pasture quality.
3. The hypothetical farm as in strategy 1 but with introduction of a 1<sup>st</sup> cycle ewe policy; mating all five years old ewes on March 20 for 20<sup>th</sup> August lambing; drop 2 paddocks out of last round to build cover for spring.
4. A combination of strategies 2 and 3; i.e. including cattle and a 1<sup>st</sup> cycle ewe mob
5. Strategy 3 but with introduction of 2 paddocks of switch pasture and 3 of lucerne; convert 1 renewal paddock from leaf turnip to rape under-sown with new pasture; 1<sup>st</sup> cycle ewe policy at 12.5% of ewes mated to lamb 13<sup>th</sup> August, no cattle.
6. Strategy 4 with introduction of 2 paddocks of switch pasture and 3 of lucerne.
7. Similar to strategy 5 but with increased proportion of the farm in switch pastures (5 paddocks) and lucerne (4 paddocks); convert 1 renewal paddock from leaf turnip to rape under-sown with new pasture; 1<sup>st</sup> cycle ewe policy at 18.5% of ewes, no cattle.

Strategies 2 and 7 run at 14 SR represent the grass and legume farm units respectively in the SISST. Each of the 7 strategic risk management policies were evaluated at 10, 12, 14 and 16 stocking rates (SR; SU ha<sup>-1</sup>) resulting in 28 potentially flexible risk management

strategies. Each of the 28 strategies was evaluated over a period of 19 years of climate and price data described above, with the first four years discarded to allow for initial conditions and the remaining 15 years in each case compared in the analysis described in sections 8.5 – 8.7.

#### **8.4. Tactical Responses**

Each of the 28 strategies with results obtained without incorporating tactical adjustments (strategies 1-7 at four SR) were then re-run with variable rather than fixed responses triggered at 15.0, 12.5 and 10.0% soil moisture levels (SML) in the top 25 cm. Whenever SML fell below each of the three trigger levels in turn, three and four ranked destocking responses for the grass and legume farms respectively were initiated under each strategy.

The following are the variable responses to a fall to the trigger moisture levels:

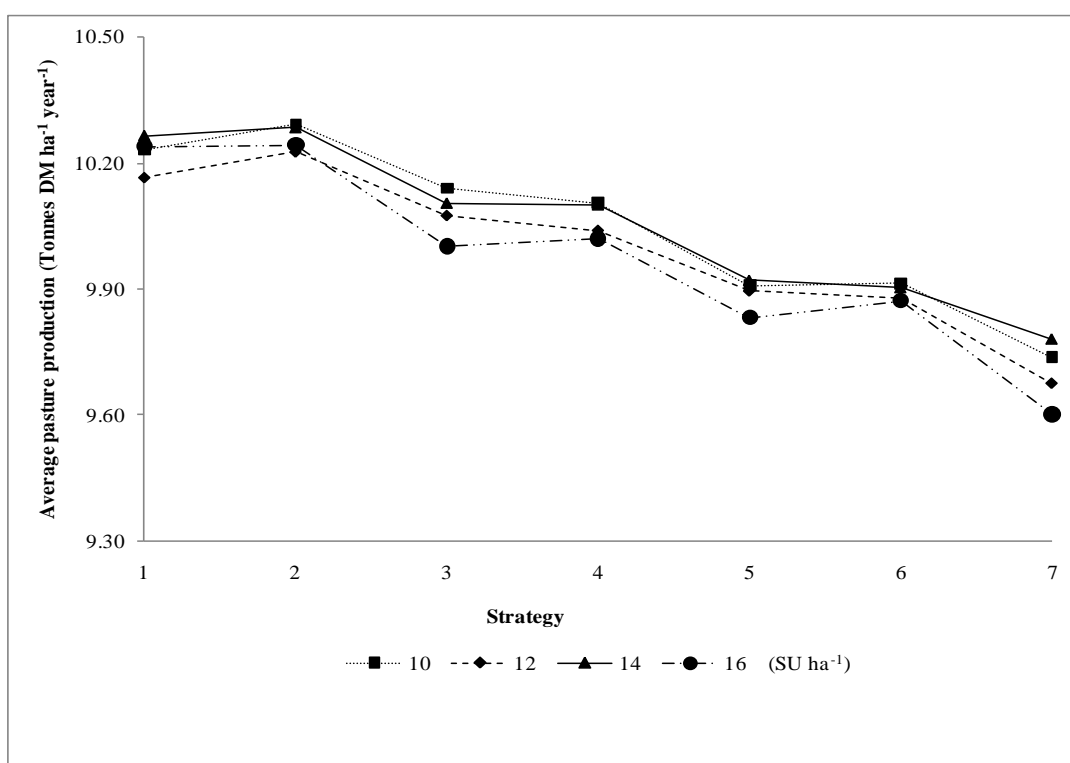
- (1) begin 1<sup>st</sup> rank destocking options: sell cattle with 10 days delay (grass farm); and wean 1<sup>st</sup> cycle mob, draft lambs, sell ewes with 10 days delay (legume farm)
- (2) begin 2<sup>nd</sup> rank destocking options: wean 1<sup>st</sup> cycle mob, draft lambs, sell ewes with 10 days delay (grass farm); and wean main mob, draft lambs, sell any cull ewes and store lambs with 10 days delay (legume farm)
- (3) begin 3<sup>rd</sup> rank destocking options: wean main mob, draft lambs, sell any cull ewes and store lambs with 10 days delay (grass farm); and review lamb retention, check feed available for ewes (calculate requirement to end of February based on zero growth rate, including designated lamb feed and determine any land available for lambs); retain only those lambs that can be finished after allowing for ewe requirements (legume farm).
- (4) begin 4<sup>th</sup> rank destocking option for grass farm: review lamb retention by checking feed available for ewes (calculate requirement to end of February based on zero growth rate, including designated lamb feed and determine any land available for lambs); retain only those lambs that can be finished after allowing for ewe requirements.

The 2<sup>nd</sup> rank destocking strategy for the grass farm (that is— wean 1<sup>st</sup> cycle ewes, draft lambs and sell ewes) becomes the 1<sup>st</sup> rank destocking option for the legume farm since cattle were not used as a flexibility option on the legume farm. Results for alternative climatic variability policies without/with inclusion of tactical responses in risk management strategies are presented below.

## 8.5. Results

### 8.5.1. Annual pasture production

Figure 8-4 shows pasture production (t DM ha<sup>-1</sup> year<sup>-1</sup>) for strategies 1-7 at stocking rates (SR) of 10, 12, 14 and 16. Production ranged between 9.60 t ha<sup>-1</sup> year<sup>-1</sup> for strategy 7 at 16 SR and 10.29 t ha<sup>-1</sup> year<sup>-1</sup> for strategy 2 at 10 SR. Production varied between strategies and SRs. Generally, 14 SR resulted in higher pasture production compared to 10, 12 and 16 SR for strategies 1-7. In all strategies, 16 SR recorded the lowest pasture production with strategy 7 at 16 SR resulting in the least pasture production overall.



**Figure 8-4:** Pasture production for strategies 1-7 at 10, 12, 14 and 16 SR

Strategies 5, 6 and 7 (utilising switch pasture system and increased area in lucerne) generally resulted in less pasture production than strategies 1, 2, 3 and 4 (utilising conventional pasture mixes for the Canterbury region of grass-clover), which is consistent with the Silverwood trial results where average pasture production on the grass unit was 10.414 t ha<sup>-1</sup> year<sup>-1</sup> with 10.336 t ha<sup>-1</sup> year<sup>-1</sup> on the legume unit. In highly stocked systems it would be expected that more pasture was consumed relative to production while the converse would be true in systems with low stocking rates. It is noteworthy that strategies 5, 6 and 7 were specifically designed to provide high quality pasture for fast lamb growth rather than increased pasture production (increased quantity); however, the quality came with an increased cost in pasture establishment.

### 8.5.2. Lambing percentage

Table 8-1 shows lambing percentage for strategies 1-7 at 10, 12, 14 and 16 SR. Lambing percentage, which was estimated as the number of lambs weaned divided by the number of ewes mated, ranged between 101.17% for strategy 4 at 10 SR and 124.41% for strategy 5 at 14 SR. The values presented in Table 8-1 are generally slightly lower than those obtained at the Silverwood trials which ranged between 106.6-136.6%; Bywater *et al.* (2010). However, following inclusion of tactical adjustments to climatic variability, the lambing percentage averaged 137.07% across all strategies and SR. Generally, coefficients of variability (CV) for lambing percentage increased with increase in SR.

**Table 8.1:** Lambing percentage for strategies 1-7 without incorporating tactical adjustments to climatic variability (the italicized values in parenthesis are coefficient of variation)

Strategy <sup>1</sup>	SR (SU ha <sup>-1</sup> )			
	10	12	14	16
1	117.18 (0.43)	118.31 (0.86)	122.37 (1.81)	120.40 (2.86)
2	113.79 (0.31)	124.02 (0.61)	118.66 (1.08)	115.80 (1.21)
3	102.05 (0.63)	103.42 (0.42)	102.64 (1.19)	102.16 (1.82)
4	101.17 (0.63)	101.65 (0.82)	106.22 (1.82)	104.23 (2.14)
5	122.13 (1.41)	124.11 (1.46)	124.41 (1.86)	118.97 (2.45)
6	114.66 (0.77)	118.23 (1.76)	120.13 (2.13)	118.58 (2.89)
7	113.87 (0.54)	116.60 (0.89)	117.61 (1.62)	115.02 (2.40)

<sup>1</sup>See text for description of the strategies

<sup>2</sup>SR, stocking rate; SU, stock units

### 8.5.3. Meat and wool production

Table 8-2 shows net carcass weight and greasy wool production per hectare for strategies 1-7 at 10, 12, 14 and 16 SR. Meat production ranged between 204.16 and 438.16 kg ha<sup>-1</sup> for strategy 1 at 10 SR and strategy 6 at 16 SR respectively. Total carcass meat production in the SISST ranged from 305.26 kg ha<sup>-1</sup> to 410.08 kg ha<sup>-1</sup>. Greasy wool production ranged between 45.61 and 102.20 kg ha<sup>-1</sup> for strategy 6 at 10 SR and strategy 1 at 16 SR respectively. As the SR increased from 10 to 16 so did wool production. As expected, strategies incorporating cattle as a flexibility option (2, 4 and 6) had low wool production on a per hectare basis.

**Table 8.2:** Meat and wool production for strategies 1-7 at 10, 12, 14 and 16 SR without incorporating tactical adjustments to climatic variability (italicized values in parenthesis are coefficient of variation)

Strategy <sup>1</sup>	Meat production (kg ha <sup>-1</sup> )				Wool production (kg ha <sup>-1</sup> )			
	SR (SU ha <sup>-1</sup> ) <sup>2</sup>				SR (SU ha <sup>-1</sup> ) <sup>2</sup>			
	10	12	14	16	10	12	14	16
1	204.16 <i>(12.02)</i>	245.04 <i>(12.24)</i>	301.62 <i>(12.99)</i>	350.18 <i>(22.85)</i>	62.90 <i>(1.51)</i>	75.24 <i>(1.53)</i>	90.45 <i>(2.01)</i>	102.20 <i>(3.15)</i>
2	238.63 <i>(5.00)</i>	306.54 <i>(28.34)</i>	342.30 <i>(7.55)</i>	370.23 <i>(7.83)</i>	47.91 <i>(1.23)</i>	52.78 <i>(5.46)</i>	67.06 <i>(1.19)</i>	69.46 <i>(2.00)</i>
3	249.58 <i>(27.44)</i>	295.05 <i>(12.36)</i>	337.14 <i>(13.07)</i>	390.63 <i>(48.50)</i>	61.16 <i>(0.99)</i>	71.14 <i>(1.85)</i>	80.35 <i>(2.39)</i>	91.92 <i>(2.73)</i>
4	275.73 <i>(8.00)</i>	336.31 <i>(10.15)</i>	375.30 <i>(15.39)</i>	412.21 <i>(11.07)</i>	56.06 <i>(1.80)</i>	64.98 <i>(2.08)</i>	54.03 <i>(7.23)</i>	56.84 <i>(7.50)</i>
5	275.85 <i>(17.50)</i>	309.48 <i>(21.33)</i>	339.90 <i>(13.14)</i>	350.28 <i>(29.04)</i>	64.13 <i>(2.83)</i>	71.93 <i>(4.55)</i>	57.69 <i>(11.99)</i>	78.91 <i>(6.51)</i>
6	319.60 <i>(13.52)</i>	380.71 <i>(9.18)</i>	386.74 <i>(12.71)</i>	438.16 <i>(13.35)</i>	45.61 <i>(2.30)</i>	53.74 <i>(2.65)</i>	60.08 <i>(3.74)</i>	67.77 <i>(6.02)</i>
7	239.91 <i>(14.21)</i>	267.38 <i>(17.47)</i>	251.95 <i>(39.49)</i>	239.82 <i>(48.49)</i>	54.03 <i>(4.43)</i>	58.47 <i>(7.61)</i>	65.40 <i>(11.55)</i>	64.75 <i>(13.25)</i>

<sup>1</sup>See text for description of the strategies

<sup>2</sup>SR, stocking rate; SU, stock units

In all cases, an increase in SR resulted in an increase in meat and wool production except for Strategy 7 where increasing SR from 12 to either 14 or 16 resulted in a decrease in meat production. The decrease was accompanied by a drastic increase in corresponding coefficients of variation. Coefficients of variation for meat and wool production also increased whenever SR was increased.

### 8.5. Effect of Including Tactical Responses within Strategies on Production

Incorporating tactical responses in risk management had effects on the lambing percentage, wool and meat production. On average, lambing percentage increased by approximately 20.0% across strategies and SR to average 137.07%. This partly explains the increase in meat production presented in Table 8-3 which resulted in an increase in GM. However, only changes in meat production are presented here as the differences in lambing percentage between strategies and SRs following inclusion of tactical adjustments to climatic variability were small (ranged between 136.72 to 138.35%). Additionally, the slight increase obtained in wool production did not have much influence on the final economic analysis of the alternative risk management strategies. It is noteworthy that wool accounted for only 11.0% of the farm income for the strategies evaluated in this study. Furthermore, the main focus in a finishing sheep system is harvesting as much meat per unit area of the farm as possible.

Table 8-3 shows the increases in meat yield for strategies 1-7 at 10, 12, 14 and 16 SR due to inclusion of tactical responses in risk management. The increase ranged between 30.16

kg ha<sup>-1</sup> (for strategy 1 at 10 SR and 15.0% SML) and 122.18 kg ha<sup>-1</sup> (for strategy 4 at 16 SR and 10.0% SML).

**Table 8.3:** Increase in average meat yield for strategies 1-7 at 10, 12, 14 and 16 SR with inclusion of tactical responses at trigger levels of 10.0, 12.5 and 15.0% volume of soil moisture in top 25.0 cm soil

Strategy <sup>1</sup>	Soil moisture level (%)	Meat production (kg ha <sup>-1</sup> )			
		SR (SU ha <sup>-1</sup> )			
		10	12	14	16
1	10.0	46.43	57.27	63.17	81.80
	12.5	46.99	68.35	64.71	63.65
	15.0	30.16	49.44	51.53	55.84
2	10.0	87.78	90.61	98.16	113.79
	12.5	67.45	72.27	87.68	93.22
	15.0	45.35	56.43	64.58	79.50
3	10.0	63.33	74.11	88.16	107.79
	12.5	55.61	63.97	79.87	89.85
	15.0	41.25	52.18	58.27	61.92
4	10.0	96.80	97.49	101.43	122.18
	12.5	75.13	82.71	89.55	100.74
	15.0	58.47	60.65	66.31	80.52
5	10.0	76.84	84.42	97.37	112.84
	12.5	58.22	75.22	83.78	90.13
	15.0	42.73	46.88	54.23	79.08
6	10.0	84.46	89.27	98.18	100.93
	12.5	68.22	70.65	61.64	81.97
	15.0	49.75	47.96	56.66	70.01
7	10.0	72.04	79.58	90.92	105.06
	12.5	52.69	58.29	74.62	86.74
	15.0	41.28	48.53	62.09	71.43

<sup>1</sup>See text for description of the strategies; <sup>2</sup>SR, stocking rate; SU, stock units

As seen from the results, the meat yield increase followed a clear pattern where delaying destocking in response to a drop in the trigger value of SML in the top 25.0 cm soil from 15.0-10.0% resulted in higher increases in yield except for strategy 1 at all SRs. The opposite trend in strategy 1 might be expected as this strategy did not incorporate any flexibility option.

## 8.7. Profit and risk

Table 8-4 shows a sample gross margin (GM) report for strategy 4 at 16 SR calculated from a series of fifteen consecutive years. Input and output prices and costs data were obtained from financial budget manuals (Financial Budget Manuals for the period 1994-2010) for the Canterbury region of New Zealand.

**Table 8.4:** A sample gross margin report; results were averaged over fifteen years period. Range figures represent the minimum and maximum for each row obtained over fifteen years period

	Mean	Range		SD
		Max.	Min.	
Stocking rate: 14 SU ha <sup>-1</sup>				
Summary of years 5-19				
<b>Income (\$ ha<sup>-1</sup>)</b>				
Lambs				
Works	803.69	997.50	507.62	171.91
Store	574.23	851.55	303.40	166.72
Cull ewes	102.70	131.69	59.73	24.16
Cattle <sup>1</sup>	647.35	888.02	440.14	178.70
Wool	241.58	308.01	163.70	33.69
<b>Total income (\$ ha<sup>-1</sup>)</b>	<b>2,369.55</b>			
<b>Expenses (\$ ha<sup>-1</sup>)</b>				
Stock				
Replacements	230.28	286.62	174.09	75.16
18-Months-heifers	338.64	406.80	245.52	101.75
Interest cost of stock	55.75	73.96	31.29	14.40
<b>Total</b>	<b>624.67</b>			
Animal Health	56.96	73.39	44.60	8.68
Breeding	27.47	41.73	16.03	4.12
Shearing	117.86	175.26	101.79	22.99
Freight	55.33	72.70	41.72	10.57
Vehicle expenses (excluding fuels)	5.09	6.06	4.31	0.48
Contractors	9.26	12.24	7.08	1.90
Seed	15.37	16.97	11.06	1.49
Cultivation (Diesel + Equipment R&M)	51.28	42.76	30.28	12.85
Weed and Pest	108.86	114.77	80.82	13.07
Fertiliser	48.05	53.94	30.29	11.63
Commission	96.87	130.11	71.77	20.31
<b>Total Direct Costs (\$ ha<sup>-1</sup>)</b>	<b>592.40</b>			
<b>Gross Margin (\$ ha<sup>-1</sup>)</b>	<b>1,152.48</b>	1497.49	941.71	219.3
<b>Stock numbers (1 July; head)</b>				
Ewes	1095	1172	977	78
Rams	20	20	20	0
Cattle	72	72	72	0
Lambs	0	0	0	0

<sup>1</sup>In strategies using cattle as flexibility option

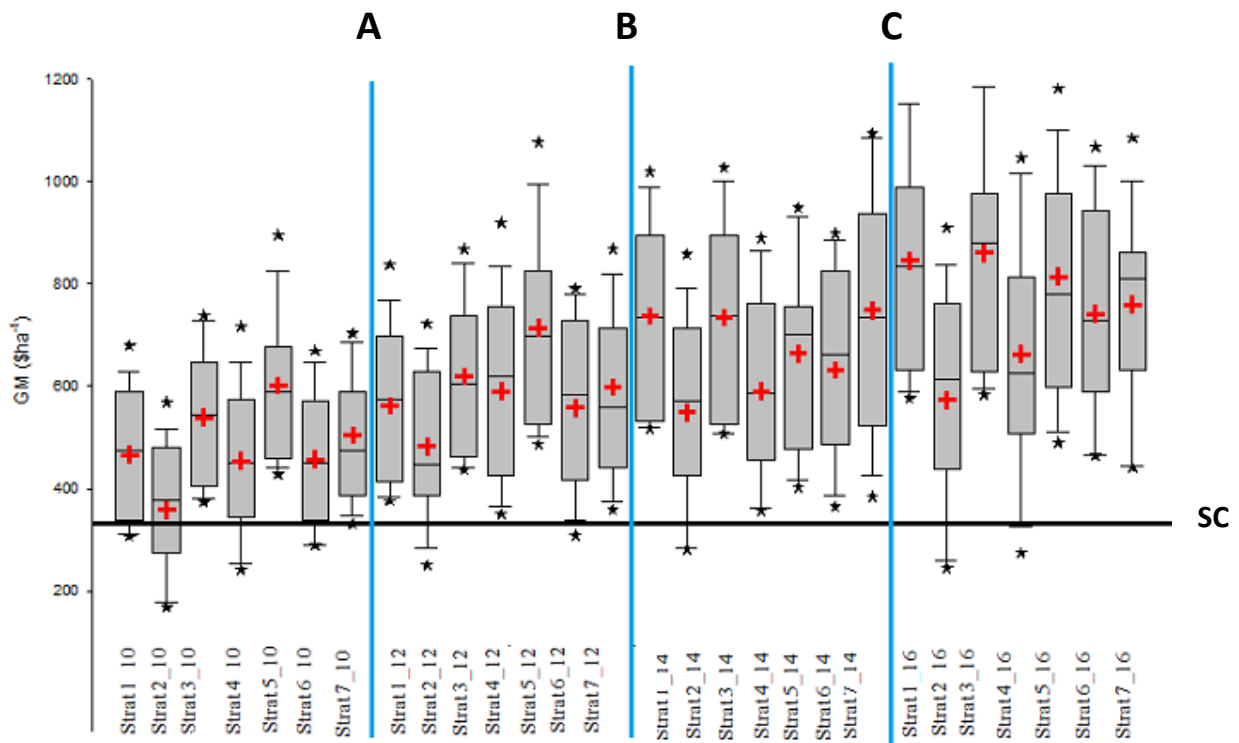
Table 8-5 presents annual GM for alternative risk management strategies without inclusion of tactical adjustments to climatic variability. Income mainly came from sale of lambs, cull ewes, wool and cattle (in strategies utilising cattle as a flexibility option). Income variation was highest in cattle followed by lambs sold to the works. In all cases, purchase of cattle (18-months-heifers) varied most in expenses category.

**Table 8.5:** Gross margin (\$ ha<sup>-1</sup>) for strategies 1-7 at 10, 12, 14 and 16 SR without tactical adjustments to climatic variability (italicised values in parentheses are coefficients of variation)

Strategy <sup>1</sup>	SR (SU ha <sup>-1</sup> )			
	10	12	14	16
1	472.46 <i>(27.33)</i>	544.92 <i>(25.93)</i>	712.68 <i>(23.98)</i>	817.92 <i>(24.44)</i>
2	537.31 <i>(26.73)</i>	604.96 <i>(24.05)</i>	807.96 <i>(24.44)</i>	789.25 <i>(25.87)</i>
3	524.28 <i>(23.73)</i>	599.20 <i>(23.35)</i>	713.37 <i>(24.21)</i>	836.91 <i>(24.16)</i>
4	539.25 <i>(30.47)</i>	570.81 <i>(29.01)</i>	694.65 <i>(29.51)</i>	827.94 <i>(34.21)</i>
5	582.16 <i>(23.63)</i>	621.74 <i>(24.64)</i>	639.78 <i>(25.81)</i>	786.63 <i>(26.87)</i>
6	529.61 <i>(28.78)</i>	605.16 <i>(28.61)</i>	644.64 <i>(28.19)</i>	799.04 <i>(27.32)</i>
7	489.21 <i>(24.43)</i>	580.22 <i>(26.33)</i>	625.29 <i>(30.33)</i>	734.58 <i>(24.25)</i>

<sup>1</sup>See text for the description of the strategies

Figure 8-5 further shows annual GM for alternative risk management strategies without inclusion of tactical adjustments to climatic variability. The average GM is represented by the red plus (+) symbol while the box represents the upper and lower quartile around the median. The ‘whiskers’ above and below the box represent the statistical extremes of the distribution while outliers are presented by the star symbol (\*). In this study, risk is comprised of both a ‘down-side’ resulting from poor seasons and an ‘up-side’ resulting from good seasons. The light blue bold lines labelled A, B, C are used to separate the GMs based on SR to improve the graph visualisation only.



**Figure 8-5:** Gross margin for strategies 1-7 at 10, 12, 14 and 16 SRs

Increasing the SR from 10 to 16 resulted in an increase in enterprise profitability. Strategy 2 at 10 SR resulted in least profitability (the distance between the standing charges (denoted by SC) and the average GM (+ symbol)). Conversely, strategy 3 at 16 SR resulted in the highest profitability relative to other strategies tested in this study. Generally, strategies 1-7 at 14 SR tended to have the ‘up-side’ exceeding the ‘down-side’ and downside outliers falling above the SC line except for strategy 2 at 14 SR.

Table 8-6 shows the GM for strategies 1-7 at 10, 12, 14 and 16 SR with tactical responses at trigger levels of 10.0, 12.5 and 15.0% SML. Gross margin increases as SR increases from 10 to 16. Generally a drop in GM was obtained when trigger SML was increased to 15.0% from 10.0 and 12.5%; however, the drop in GM was accompanied by corresponding decrease in CV. In other words, a more conservative approach to tactical adjustments (a higher SML trigger level) results in lower average returns but less risk.

**Table 8.6:** Gross margin for Strategies 1-7 at 10, 12, 14 and 16 SR with tactical adjustments to climatic variability (italicised values in parentheses are coefficients of variation)

Strategy <sup>1</sup>	Soil moisture level (%)	SR (SU ha <sup>-1</sup> )			
		10	12	14	16
1	10.0	560.56 <i>(13.47)</i>	701.91 <i>(14.58)</i>	810.56 <i>(16.26)</i>	1043 <i>(19.58)</i>
	12.5	519.33 <i>(12.92)</i>	602.10 <i>(14.15)</i>	826.04 <i>(15.07)</i>	932.70 <i>(18.33)</i>
	15.0	487.28 <i>(12.40)</i>	592.70 <i>(12.28)</i>	798.89 <i>(12.36)</i>	867.99 <i>(12.58)</i>
2	10.0	626.33 <i>(17.50)</i>	801.83 <i>(16.90)</i>	972.97 <i>(17.92)</i>	1064.23 <i>(19.57)</i>
	12.5	577.42 <i>(11.30)</i>	749.17 <i>(11.78)</i>	875.84 <i>(12.51)</i>	962.19 <i>(13.33)</i>
	15.0	568.85 <i>(9.94)</i>	682.15 <i>(10.12)</i>	852.64 <i>(10.31)</i>	950.11 <i>(11.17)</i>
3	10.0	672.61 <i>(16.16)</i>	723.22 <i>(15.84)</i>	849.42 <i>(16.42)</i>	1168.17 <i>(19.39)</i>
	12.5	610.05 <i>(9.36)</i>	758.64 <i>(12.73)</i>	872.76 <i>(13.20)</i>	1099.65 <i>(14.18)</i>
	15.0	574.43 <i>(10.25)</i>	698.05 <i>(10.06)</i>	844.00 <i>(10.47)</i>	939.71 <i>(11.44)</i>
4	10.0	675.48 <i>(15.16)</i>	797.13 <i>(17.23)</i>	910.22 <i>(15.59)</i>	1172.95 <i>(18.15)</i>
	12.5	618.21 <i>(15.54)</i>	697.77 <i>(12.31)</i>	851.00 <i>(11.26)</i>	1017.64 <i>(13.19)</i>
	15.0	598.72 <i>(10.07)</i>	668.21 <i>(10.27)</i>	793.04 <i>(9.66)</i>	891.53 <i>(11.16)</i>
5	10.0	646.34 <i>(14.98)</i>	763.04 <i>(15.55)</i>	825.86 <i>(16.28)</i>	969.86 <i>(19.95)</i>
	12.5	637.40 <i>(12.42)</i>	719.59 <i>(12.43)</i>	803.13 <i>(13.08)</i>	898.04 <i>(14.65)</i>
	15.0	613.63 <i>(10.21)</i>	680.64 <i>(10.07)</i>	763.33 <i>(10.23)</i>	864.73 <i>(12.73)</i>
6	10.0	668.18 <i>(15.32)</i>	814.81 <i>(15.10)</i>	827.32 <i>(15.78)</i>	1063.80 <i>(18.48)</i>
	12.5	589.48 <i>(11.54)</i>	767.55 <i>(12.58)</i>	791.76 <i>(13.37)</i>	881.92 <i>(16.90)</i>
	15.0	578.95 <i>(11.55)</i>	737.32 <i>(11.54)</i>	760.10 <i>(11.93)</i>	875.93 <i>(12.54)</i>
7	10.0	581.90 <i>(15.46)</i>	644.23 <i>(16.60)</i>	747.19 <i>(15.29)</i>	912.08 <i>(19.13)</i>
	12.5	540.54 <i>(13.36)</i>	641.10 <i>(14.36)</i>	704.52 <i>(13.22)</i>	859.84 <i>(16.54)</i>
	15.0	525.28 <i>(11.61)</i>	657.49 <i>(12.47)</i>	666.71 <i>(11.48)</i>	781.52 <i>(12.36)</i>

<sup>1</sup>See text for description of the strategies; <sup>2</sup>SR, stocking rate; SU, stock units

Further observation made from the results presented in Table 8-6 indicates that the CV of the GM usually increases with an increase in SR; i.e. increasing the stocking rate increases risk. However, the rate of increase varies between trigger moisture levels and is highest in strategies where tactical responses are triggered by a drop of SML to 10.0% in the top 25.0

cm soil. Tactical responses triggered when SML drops to 15.0% result in the least change in CV between 10, 12, 14 and 16 SR. Again this indicates that a more aggressive stance in terms of tactical adjustments (waiting until SML reaches the effective wilting point) increases the average return, but also increases the risk.

An analysis of variance for GM and risk were carried out with strategy, SR and SML as factors. Tables 8-7 and 8-8 present summary statistics of variance analysis for GM and risk respectively. The results for GM indicate that the overall model is statistically significant ( $F = 5.479$ ,  $p < 0.000$ ). The variables SR and SML are also statistically significant ( $F = 37.687$ ,  $p < 0.000$  and  $F = 10.603$ ,  $p < 0.000$ , respectively). However, variable strategy is not statistically significant ( $F = 1.021$ ,  $p < 0.366$ ) ( $P < 0.05$ ). Similarly, all the interactions (Strategy\*SR, Strategy\*SML, SR\*SML and Strategy\*SR\*SML) are not statistically significant ( $P < 0.05$ ).

**Table 8.7:** Summary analysis of variance statistics for GM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.280E6 <sup>1</sup>	47	48510.474	5.479	.000
Intercept	3.957E7	1	3.957E7	4468.497	.000
Strategy	18074.717	2	9037.358	1.021	.366
SR	1001128.350	3	333709.450	37.687	.000
SML	281670.364	3	93890.121	10.603	.000
Strategy*SR	101767.896	6	16961.316	1.916	.092
Strategy*SML	54359.782	6	9059.964	1.023	.418
SR*SML	8916.101	9	990.678	.112	.999
Strategy*SR*SML	59843.985	18	3324.666	.375	.988
Error	566698.366	64	8854.662		
Total	5.785E7	112			
Corrected Total	2846690.631	111			

<sup>1</sup>R Squared = 0.801 (Adjusted R Squared = 0.655)

The results for analysis of variance of risk shows that variables SR and SML are statistically significant ( $F = 231.512$ ,  $p < 0.000$  and  $F = 663.531$ ,  $p < 0.000$ , respectively). But similar to the results for GM analysis, variable strategy is not statistically significant ( $F = 0.853$ ,  $p < 0.431$ ). However, unlike the GM analysis, strategy\*SR and SR\*SML are statistically significant ( $F = 19.008$ ,  $p < 0.000$  and  $F = 6.913$ ,  $p < 0.000$ , respectively). But like the GM, interactions strategy\*SML, and strategy\*SR\*SML are not statistically significant ( $P < 0.05$ ).

**Table 8.8:** Summary analysis of variance statistics for risk

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	189524.026 <sup>1</sup>	47	4032.426	81.278	.000
Intercept	1131234.417	1	1131234.417	22801.197	.000
Strategy	84.648	2	42.324	.853	.431
SR	34457.990	3	11485.997	231.512	.000
SML	98759.182	3	32919.727	663.531	.000
Strategy*SR	5658.142	6	943.024	19.008	.000
Strategy*SML	228.545	6	38.091	.768	.598
SR*SML	3086.786	9	342.976	6.913	.000
Strategy*SR*SML	558.524	18	31.029	.625	.866
Error	3175.228	64	49.613		
Total	1720213.142	112			
Corrected Total	192699.254	111			

<sup>1</sup>R Squared = .984 (Adjusted R Squared = .971)

As noted, both GM and risk increase with stocking rate and reduce with SML— that is, responding at 10% moisture in the top 25 cm of soil is more risky, but generates greater average returns than responding at 15% SML. However, the analysis of variance also indicates that changes in both GM and risk with stocking rate depend on the underlying strategy and the trigger SML value.

Table 8-9 shows the percentage increase in GM for strategies 1-7 at 10, 12, 14 and 16 SR with inclusion of tactical responses in risk management. The differences represent the cost of failing to incorporate tactical adjustment to climatic variability in risk management strategies. The difference ranged between 3.14% for strategy 1 at 10 SR with trigger SML at 10.0% and 39.65% for strategy 4 at 12 SR and trigger SML at 10.0% of the top 25.0 cm. The difference is mainly attributable to a combination of increased productivity during better than average pasture growing years (increased profit) and decreased losses during worse than average pasture growing years (decreased loss).

**Table 8.9:** Percentage increase in gross margin between corresponding strategies 1-7 at 10, 12, 14 and 16 SR with inclusion of tactical responses at 10, 12.5 and 15.0% SML by volume in top 25.0 cm soil)

Strategy <sup>1</sup>	Soil moisture level (%)	SR (SU ha <sup>-1</sup> )			
		10	12	14	16
1	10.0	18.65	28.81	13.73	27.52
	12.5	9.92	10.49	15.91	14.03
	15.0	3.14	8.77	12.10	6.12
2	10.0	16.57	32.54	20.42	34.84
	12.5	7.46	23.84	8.40	21.91
	15.0	5.87	12.76	5.53	20.38
3	10.0	28.29	20.70	19.07	39.58
	12.5	16.36	26.61	22.34	31.39
	15.0	9.57	16.50	18.31	12.28
4	10.0	25.26	39.65	31.03	33.60
	12.5	14.64	22.24	22.51	15.91
	15.0	11.03	17.06	14.16	7.68
5	10.0	11.02	22.73	29.08	23.29
	12.5	9.49	15.74	25.53	14.16
	15.0	5.41	9.47	19.31	9.93
6	10.0	26.16	34.64	28.34	33.13
	12.5	11.30	26.83	22.82	10.37
	15.0	9.32	21.84	17.91	9.62
7	10.0	18.95	11.03	19.49	24.16
	12.5	10.49	10.49	12.67	17.05
	15.0	7.37	13.32	6.62	6.39

<sup>1</sup>See text for description of the strategies; <sup>2</sup>SR, stocking rate; SU, stock units

Table 8-10 shows the percentage decrease in coefficient of variation for the gross margin (i.e. risk) between corresponding strategies with inclusion of tactical responses to a drop in SML to 10.0, 12.5 and 15.0% in the top 25.0 cm soil at 10, 12, 14 and 16 SR. There was considerable decrease in CV between corresponding strategies with and without inclusion of tactical adjustments to climatic variability. The decrease ranged between 19.74 for strategy 3 at 16 SR with trigger SML at 10.0% and 67.38% for strategy 4 at 16 SR and trigger SML at 15.0% of the top 25.0 cm.

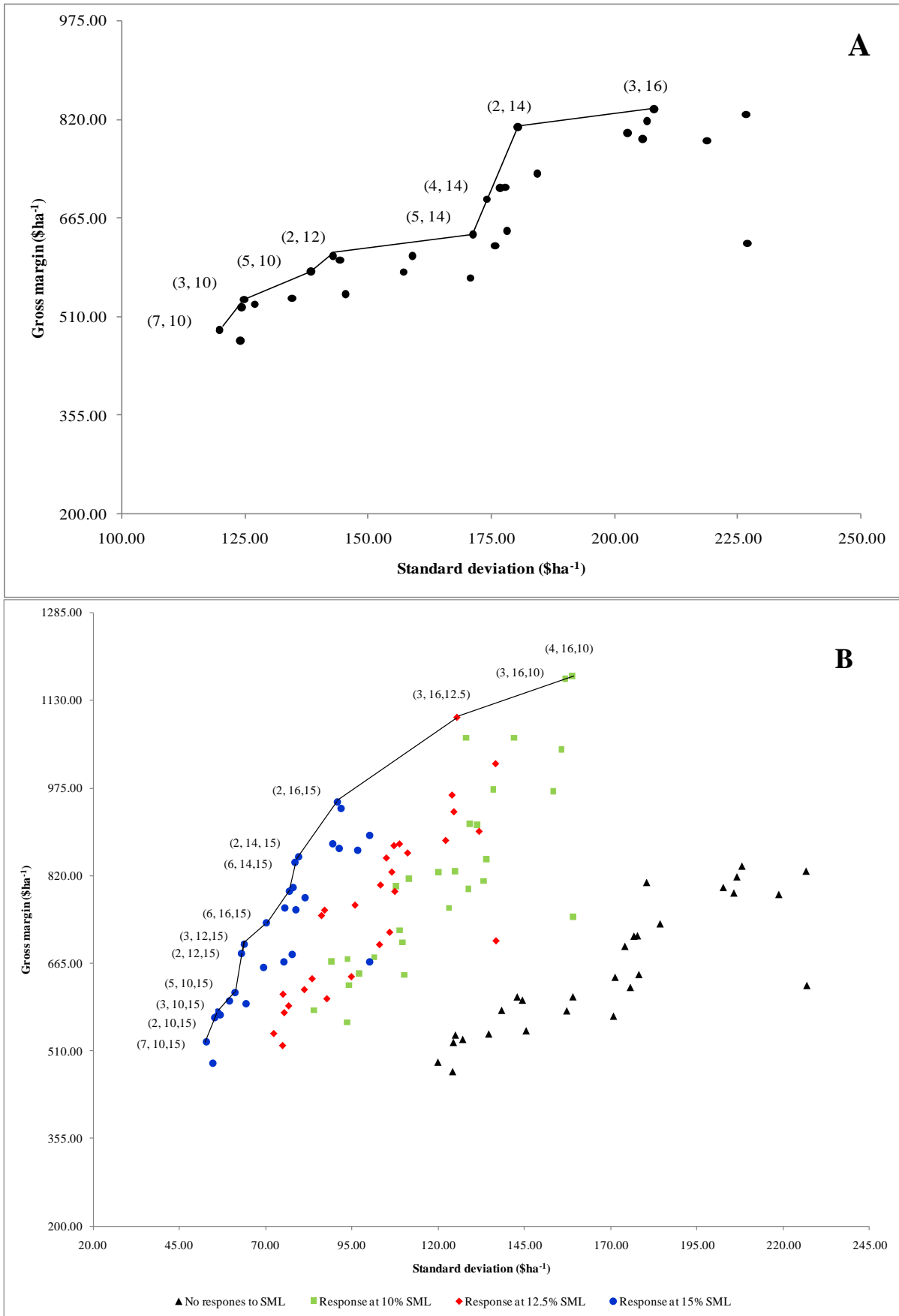
**Table 8.10:** Percentage decrease in coefficients of variation between corresponding strategies 1-7 at 10, 12, 14 and 16 SR with inclusion of tactical responses at 10, 12.5 and 15.0% SML by volume in top 25.0 cm soil)

Strategy <sup>1</sup>	Soil moisture level (%)	SR (SU ha <sup>-1</sup> )			
		10	12	14	16
1	10.0	50.71	43.77	32.19	19.89
	12.5	52.73	45.43	37.16	25.00
	15.0	54.63	52.64	48.46	48.53
2	10.0	34.53	29.73	26.68	24.35
	12.5	57.73	51.02	48.81	48.47
	15.0	62.81	57.92	57.82	56.82
3	10.0	31.90	32.16	32.18	19.74
	12.5	60.56	45.48	45.48	41.31
	15.0	56.81	56.92	56.75	52.65
4	10.0	50.25	40.61	47.17	46.95
	12.5	49.00	57.57	61.84	61.44
	15.0	66.95	64.60	67.27	67.38
5	10.0	36.61	36.89	36.92	25.75
	12.5	47.44	49.55	49.32	45.48
	15.0	56.79	59.13	60.36	52.62
6	10.0	46.77	47.22	44.02	32.36
	12.5	59.90	56.03	52.57	38.14
	15.0	59.87	59.66	57.68	54.10
7	10.0	36.72	36.95	49.59	21.11
	12.5	45.31	45.46	56.41	31.79
	15.0	52.48	52.64	62.15	49.03

<sup>1</sup>See text for description of the strategies; <sup>2</sup>SR, stocking rate; SU, stock units

Figures 8-6 shows the risk-efficient frontiers for strategies 1-7 at 10, 12, 14 and 16 SR without (A) and with (B) including tactical adjustments to climatic variability. The frontiers show the best possible combinations of expected GM ( $E_p$ ) and risk (measured as the standard deviation of the GM) in relation to alternative management strategies. Any strategy whose outcome in terms of risk and expected GM does not lie on the frontier is inefficient as a higher  $E_p$  can be obtained for the same level of risk by moving vertically to another management strategy on the frontier, or the same  $E_p$  can be obtained with a lower level of risk by moving horizontally to the frontier. Each point on the frontier represents a different management strategy. Within the experimental set of treatments studied here, risk efficient management strategies combinations (S, SR) (7, 10), (3, 10), (5, 10), (2, 12), (5, 14), (4, 14), (2, 14) and (3, 16) were identified as being more efficient where tactical adjustments in risk management policies were ignored. The efficient risk management strategies combinations (S, SR, SML) varied when tactical responses were considered and they were (2, 10, 15), (7, 10, 15), (2, 10, 15), (3, 10, 15), (5, 10, 15), (2, 12, 15), (3, 12, 12.5), (6, 16, 15), (6, 14, 15), (2, 14, 15), (2, 16, 15), (3, 16, 12.5), (3, 16, 10), and (4, 16, 10). As shown in Figure 8-6, the

number of strategies falling on the risk-frontier curve increased by 61.54% (that is— from 8 to 13). A further comparison between the two sets of strategies show that 6 of the 8 risk-efficient strategies without considering tactical response to climatic variability (Figure 8-6A) fell on the risk-frontier curve when tactical adjustments were included in the risk management (Figure 8-6B). Notable from Figure 8-6B is that none of the risk management strategies that did not incorporate tactical adjustments to climatic variability fell on the risk-frontier curve (that is— they were completely dominated by strategies that included tactical responses).



**Figure 8-6:** Relationship between expected gross margin and variability as measured by standard deviation for risk management without (A) and with (B) incorporation of tactical response to climatic variability

Statistical results presented in Table 8-11 indicate that there was a statistically significant difference between the mean GM for strategies with and without inclusion of tactical responses to climatic variability ( $t = -3.505$ ,  $p = 0.001$ ). Risk management strategies incorporating tactical responses to climatic variability had statistically significantly higher returns ( $\$703.42 \text{ ha}^{-1}$ ; risk-efficient frontier presented in Figure 8-6B) than when tactical adjustments were ignored ( $\$608.73 \text{ ha}^{-1}$ ; risk-efficient frontier presented in Figure 8-6A).

**Table 8.11:** Results for treatments mean difference

		Test for Equality of Variances		t-test		
		F	Sig.	t	df	Sig.
GM	Equal variances assumed	2.517	.116	-3.11	110	.002
	Equal variances not assumed			-3.51	58.33	.001
Risk <sup>1</sup>	Equal variances assumed	1.974	.163	11.02	110	.000
	Equal variances not assumed			10.02	39.99	.000

<sup>1</sup>Standard deviation of GM

Results presented in Table 8-11 further show that there was statistically significant difference between the mean risk for strategies with and without inclusion of tactical responses to climatic variability ( $t = 10.016$ ,  $p < 0.000$ ). Risk management strategies incorporating tactical responses to climatic variability had statistically significantly lower risk ( $\$100.71 \text{ ha}^{-1}$ ; risk-efficient frontier presented in Figure 8-6B) than when tactical adjustments were ignored ( $\$173.18 \text{ ha}^{-1}$ ; risk-efficient frontier presented in Figure 8-6A).

An important observation from Figure 8-6 is that, the point (SML) at which a response is triggered affects strategy profitability. An increase in SML triggers value from 10.0 to 12.5% and from 12.5% to 15% results in a decrease in GM and risk. It is clear in the context of the production circumstances considered in this study that, risk-efficient strategies were at 15.0% SML for low risk/low returns strategies, at 12.5% SML for intermediate risk/intermediate return strategies and at 10.0% SML for high risk/high return strategies as shown in Figure 8-6. This implies that destocking based on SML in the top 25.0 cm soil in high performance dryland sheep systems should occur at different trigger values (target SML) for different SRs; the more aggressive the stance in terms of stocking rate, the more aggressive the stance should be in terms of SML trigger values.

Farmers have different preferences and objectives and therefore a common choice of optimal strategy is most unlikely to hold. Firstly it is clear that farmers who intend to incorporate tactical adjustments to climatic variability in risk management strategies— all farmers respond tactically when information on uncertain occurrence becomes known— should consider incorporating flexibility options such as growing cattle or a 1<sup>st</sup> cycle ewes policy as it is clear from the risk efficient strategies that none of the strategies lying on the

risk-efficient frontier did not include either cattle or a 1<sup>st</sup> cycle ewe policy in the context of this study as shown in Figure 8-6.

Varying the severity index (SI), destocking action or stock disposal priority from values presented in Table 8-12 resulted in a decrease in enterprise profitability accompanied by a shift in the risk-frontier for the risk management strategies and production circumstances considered in this study. Feed days represent the number of days that the feed on farm can satisfy productive and reproductive nutritional requirements of the stock on hand.

**Table 8.12:** Optimal tactical decisions table used in obtaining the risk-frontier presented in Figure 8-6B

	Severity index		Destocking actions	Stock disposal priority	
	Feed days (Days)	Rainfall (mm/month)		Pre-weaning	Post-weaning
High	<30	<50	<ul style="list-style-type: none"> <li>• Sell cattle<sup>1</sup></li> <li>• Wean 1<sup>st</sup> cycle ewes</li> <li>• Sell 1<sup>st</sup> cycle ewes</li> <li>• Wean main mob ewes</li> <li>• Sell cull ewes</li> <li>• Sell finishing lambs</li> </ul>	<ul style="list-style-type: none"> <li>• Cattle<sup>1</sup></li> <li>• 1<sup>st</sup> cycle ewes</li> <li>• Cull ewes</li> <li>• Finishing lambs</li> </ul>	<ul style="list-style-type: none"> <li>• 1<sup>st</sup> cycle ewes</li> <li>• Cattle<sup>1</sup></li> <li>• Cull ewes</li> <li>• Finishing lambs</li> </ul>
Medium	<30 >60	>120 <80 but >60	<ul style="list-style-type: none"> <li>• Wean 1<sup>st</sup> cycle ewes</li> </ul>		
Low	>60 >30	>80 >120	Follow fixed management calendar of events described in Section 5.10.		

<sup>1</sup>Applied in strategies using cattle as flexibility option however the order of destocking actions and stock disposal priority remain the same except that first destock action becomes weaning of 1<sup>st</sup> cycle ewes as is the stock disposal priority

A detailed operation of the destocking algorithm which uses the variables presented in Table 8-12 is presented in Chapter 6.

### 8.8. Sensitivity of gross margin to changes in prices of meat and wool

Table 8-13 presents results of sensitivity of GM to changes in prices of meat and wool for strategy 4 with and without inclusion of tactical responses. The results indicate GM (and subsequently profitability) is sensitive to market risk (product prices and costs variability as defined in MAFF (2001)).

**Table 8.13:** Gross margin at different prices<sup>1</sup> of meat and wool for strategy 4 at 14 SR with/without inclusion of tactical responses to drop in SML to 10.0, 12.5 and 15.0% in top 25.0 cm soil

M <sup>2</sup>	Tactical response to climatic variability			
	Without	With		
		SML <sup>3</sup>		
		10.0	12.5	15.0
0.875	430.28	592.79	653.25	583.57
1.00	590.14	815.83	890.32	795.36
1.125	750.00	1033.13	1090.76	998.68
1.25	909.85	1184.72	1360.37	1212.97
Regression coefficients	1278.9M-688.72	1594.5M - 787.51	1857.4M - 974.85	1673.2M - 880.15

<sup>1</sup>Base value represents the current market price

<sup>2</sup>M represents the multiplier applied to the base price

<sup>3</sup>See text for description of the three moisture levels

As shown, the magnitude of GM variation differed between alternative SML trigger values and the price multiplier applied, with comparatively large value of the multiplier resulting in larger GM variation. Average GM increases linearly with the price multiplier with the rate of increase being higher as the base level GM (multiplier = 1) increases as shown by the regression coefficients presented in Table 8-11. This indicates that where the price multiplier applied is the same, the change differed with the inclusion and trigger values for tactical responses implying that the effect of market risk varies depending on whether tactical adjustments are incorporated in risk management and when. Inclusion of current prices within the destocking algorithm would complicate it beyond the scope of the current study. However, by using real climate and price data, this study ensured that all the variability in prices and any effect on them of prevailing climatic conditions was included in the results.

Chapter 9 below presents detailed discussion, conclusions, and recommendations for further research.

## CHAPTER 9

### Discussion, Conclusions and Further Research Recommendations

#### 9.1. The Rationale for this study

Many sources of risk influence agricultural systems, ranging from uncertainty in weather and pests to institutional risks involving changes in government policy (Hardaker *et al.*, 2004). There are a number of reasons why risk matters in farm planning. For instance, an individual's attitude to risk can influence resource allocation decisions, and choices regarding optimal input use and output levels may differ under assumptions of risk and certainty (Jones *et al.* 2006). Seasonal variability is an important source of risk faced by farmers (Jolly, 1983). Regardless of whether an individual is risk-averse or ambivalent about risk, there are options to tactically adjust farming strategies as the outcomes of risk relating to seasonal conditions and prices become known (Jones *et al.*, 2006).

Nearly 77.0% of agricultural land under use in New Zealand is grazed by livestock, making pastoral farming the dominant land use accounting for 44.0% of the total dollar value of New Zealand's exported merchandise in 2004 (Bourdôt *et al.*, 2007). Pastoral agriculture is vulnerable to climatic variability (Halloy and Mark, 2003; Thornley and Cannell, 1997) and various studies have been carried out to provide a solution to climate variability and to manage its effects, mostly providing strategic rather than tactical solutions. This research has utilised a model that evaluates alternative tactical interventions in response to climatic and price conditions as they become known and has evaluated the economic importance of incorporating tactical responses in a number of strategic risk management policies in high performance dryland sheep systems.

#### 9.2. Methodological approach

Managing grazing systems is complicated by the need to balance the dynamic nutritional requirement of different classes of livestock with a feed supply that fluctuates in quality and quantity between years (Finlayson *et al.*, 1995). The complexity and the uncertainty that occurs in such a decision making process are the major features that emphasise the importance of a systems approach to analysing agricultural systems. In this study, a total of 140 different cases (2100 years worth of data) were investigated for the analysis. This enormity justifies the use of a systems model as it would be impossible to perform this sort of experiment in the field. However, data from field experiments were used in evaluating the suitability of the model in replicating high performance dryland sheep systems.

Models have been classified into those that optimise versus those that simulate (Swinton and Black, 2000). Models that simulate are mainly used for foresight and/or policy design. They can be considered as ‘what if’ tools with the information obtained from a ‘what if’ analysis being usually more important in decision making than the knowledge of the optimal choice (Swinton and Black, 2000). Simulation models are particularly helpful in the study of processes in which time is critical especially when actions in one period have implications on outcomes in future periods. In managing embedded risk, decision made at certain points in the production season affects future decisions and outcomes which explain the importance of adopting simulation models in this study.

The LincFarm grazing sheep systems model, originally developed by Finlayson *et al.* (1995) and Cacho *et al.* (1995) was used in the study. A number of modifications to the model were required to accommodate components in the Silverwood Innovative Sheep Systems Trials (SISST) used as the basis of the risk analysis. These included parameterisation of additional species within the mechanistic pasture growth model described by Bywater *et al.* (1999) based on the methodology of Woodward (1998) and Woodward *et al.* (1998). Additional species included annual ryegrass, cocksfoot and lucerne requiring 46 pasture growth parameters presented in Table 4-1 for annual ryegrass and cocksfoot and an additional 9 parameters presented in Table 4-4 for lucerne which are mainly concerned with the root sub-model. Previous studies utilising the model included parameter values for perennial ryegrass, white and red clovers, tall fescue and chicory. The suitability of the model parameters obtained was evaluated following methods discussed by Kobayashi and Us Salam (2000).

A simple forage crop DM accumulation model was developed to simulate DM production for kale, leaf turnip and rape. The model uses the accumulated heat available defined as thermal time (Tt) (or heat units or growing degree days) to predict crop growth (Morrison *et al.* 1989; Mackenzie *et al.*, 1999; Moot *et al.*, 2007). Results from the model and field data presented in section 4.7 showed that the Tt model was able to simulate DM accumulation for kale, leaf turnip and rape adequately for the purpose of this study.

Previous implementations of the LincFarm model included only sheep and since some of the strategies considered here and in the SISST involved cattle, a dynamic post-weaning beef growth and composition model was added. This was based on the model developed by Oltjen *et al.* (1986b) from fundamental biological concepts of hyperplasia and hypertrophy described by Baldwin and Black (1979) and further developed by Oltjen *et al.* (2001, 2006). Results for LW and intakes from Kitessa (1997) experiment I were used for model parameter

estimation while data sets from Kitessa (1997) experiment II, Sainz *et al.* (1995), Greathead *et al.* (2006), and Garrett and Hinman (1969) were used in model evaluation following methods discussed by Kobayashi and Us Salam (2000). A detailed description of the beef growth and composition model is presented in Chapter 5.

In addition to the biological components added to LincFarm, a generic destocking and marketing algorithm was designed, tested and included in the model to incorporate tactical adjustments in risk management strategies in response to climatic variability. Based on the current and projected feed situation, stock type and corresponding animal numbers, and producer defined stock disposal priority, the algorithm identifies the optimal destocking options. The design, implementation and evaluation of the algorithm is presented in Chapter 6.

The performance of the extended model was evaluated against data from the SISST project at Silverwood farm at Hororata. Results for the evaluation of the extended model are presented in section 7.4. For all aspects tested, the model was shown to operate within acceptable limits and was considered sufficient to simulate alternative risk management strategies evaluated in this study.

### **9.3. Evaluation of alternative risk management strategies**

An initial analysis was carried out to compare the seven identified risk management strategies (S) without incorporating tactical responses. Each strategy was run at 10, 12, 14 and 16 SR resulting in a 2 factor (7S x 4SR) experiment. In a second level analysis, the strategies were re-run with tactical responses triggered at 10.0, 12.5 and 15.0% moisture levels (SML) in the top 25.0 cm soil resulting in a 3 factor (7S x 4SR x 3SML) experiment. The SML in top 25.0 cm soil was considered as the critical environmental variable to be monitored and the three moisture levels acted as the trigger values below which destocking actions were activated.

Each strategy at the two levels of analysis was evaluated for a period of 19 years with the first 4 years' results being discarded to eliminate the effect of initial conditions. The remaining 15 years of output were used to estimate the lambing percentage, meat and wool production, and GM. These variables formed the basis on which physical (e.g. pasture production) and economic efficiencies (e.g. profitability) of alternative risk management strategies were compared. The economic value of considering tactical responses in risk management strategies was obtained by comparing the expected GM values for the corresponding strategy with and without inclusion of tactical responses to climatic variability.

Stocking rate has been considered as the key driver of profit in grazing systems

through increasing pasture utilisation and spreading fixed costs over more production units (Holmes and Associates, 2003). This research confirms the merit of increased pasture utilisation with increase in SR; however, consistent with previous studies (Cacho and Bywater, 1994; Cacho *et al.*, 1999) pasture productivity is reduced if SR is raised too high. In the context of the production circumstances in this study, optimum SR was at 14 SU ha<sup>-1</sup> with a decrease in pasture production with SR above and below this value as shown in Figure 8-4. It is suggested that at low SR, pasture is not fully utilised, more grass is produced than eaten, and the consequence is that the overgrown grass grows more slowly and is of poor quality. Similarly, at high SR (for example at 16 SR in this circumstance) too much grass is eaten than leaving little pastures mass (cover) for optimal re-growth. Johnson and Parson (1985) observed that SR not only directly affects livestock growth rates, but also pasture production. These differences within strategies in pasture production due to grazing management (such as SR) confirm the importance of producer's decisions on pasture production and productivity.

Differences in pasture regimes (the farm area in conventional ryegrass-clover mix, lucerne and switch system pastures) caused differences between strategies in production and profitability. Comparing pasture production between strategies 5 and 6, and strategy 7 shows that less pasture was produced when more area on the farm was committed to switch and lucerne as shown in Figure 8-4. However, enterprise profitability did not drop as would be expected with a decrease in pasture production as shown in Figure 8-5 implying that the reduction in pasture productivity was compensated with higher pasture quality and subsequently faster lamb growth. Similar observations that legumes retain their quality longer than grass when left un-grazed were made by Bywater *et al.* (2010) in setting up the SISST project. These authors noted that under the legume pasture systems, pasture utilisation was more important than the strict pasture control required in the grass based systems. However, as will be shown when tactical adjustments are applied in risk management strategies, it is important in terms of profitability to strike a balance between the high costs that comes with an increased focus on pasture quality versus the corresponding economic gains from fast lamb growth. This observation is drawn from results presented in Table 8-6 which show strategy 7 (with the biggest farm area in legume pastures intended to provide more quality feed for faster lamb growth) lagging behind all other strategies at 12, 14 and 16 SR when tactical adjustment were included in risk management strategies. Cost of different pasture production regimes studied here (not presented for all strategies) showed that strategy 7 was 11.72% more costly compared to costs of pasture production for strategies 5 and 6 (next highest cost for pasture combinations considered) and 17.08% more than strategies 1, 2, 3 and 4 which all had the

base farm pasture combination.

Pasture management aspects are also important in this study from the perspective of increasing enterprise productivity and profitability and reducing risk in terms of identifying environmental variables to be monitored when deciding when and how much to destock during dry periods when faced with either current or projected feed scarcity and/or uncertain prospects of receiving useful rain.

Observation made while comparing risk managements strategies 1 and 2, 3 and 4, and 5 and 6 at 10, 12, 14 or 16 SR (each pair only differed on whether cattle was incorporated as a flexibility option) shows that inclusion of cattle in risk management strategies as a flexibility option resulted in an increase in meat production. However, comparing the same pairs for gross margin imply that the increase in meat production did not translate into increased profitability. However, in the cases where no tactical adjustments are applied in response to climatic variability, the cattle were assumed to be sold at the end of the season irrespective of the farm feed situation. This observation emphasises the importance of using cattle as a flexibility option rather than as an additional fixed production option where they may compromise enterprise profitability by worsening the animal feed demand pressure in years with poor pasture growth resulting in large financial losses especially where the farm is carrying large numbers of stock.

Comparing strategies 1 and 3 where the only difference is inclusion of a 1<sup>st</sup> cycle ewe policy shows that mating a fraction of old ewes earlier whether or not tactical adjustment are incorporated in risk management strategies results in increased meat production and GM. This explains why some farmers mate a proportion of their ewe mob to lamb earlier resulting in earlier weaning and drafting (Bywater A.C. pers. Com) and why a 1<sup>st</sup> cycle ewe policy was included in the SISST as a potential way of responding to climatic variability. The risk management strategies for the SISST were developed in collaboration with the Silverwood Farmer's Reference Group (Bywater *et al.*, 2010).

The overall objective of high performance dryland sheep systems currently is to finish as many lambs as possible assuming returns favour lambs sold to works compared to lambs sold store. However, sales from wool form an important source of income for the farm enterprise. In this study, wool production per hectare varied between strategies and SR. The production was naturally higher in strategies that did not include cattle as a flexibility option. The overall contribution of wool to the GM in this study was relatively small (at 11.0%). Thus, differences in wool production between alternative risk management strategies were less significant in evaluating the economic efficiency of the strategies.

With the risk management strategies and production circumstances considered in this study and ignoring the possibility for tactical adjustments, GM can be maximised at 16 SR, for a strategy that incorporates a 1<sup>st</sup> cycle ewe policy with approximately 25.0% of ewes (old ewes) being mated to lamb earlier with 81.25% of the farm area sown in ryegrass-clover mix (13 paddocks in this study), 6.25% in lucerne and 12.50% of pasture renewed annually, through winter (kale) and summer (barley and leaf turnip) feeds sequentially. This pasture combination represents strategy 3 at 16 SR and results in an average GM of \$861.21 ha<sup>-1</sup> per year.

Despite this high expected profitability from adopting strategy 3 at 16 SR, this might not be the best choice for every farmer, as there are differences in producers' objectives and willingness to take risk. Strategy 3 at 16 SR also resulted in the highest GM variability. In practice, most farmers do respond to prevailing conditions so a failure to include tactical adjustments in management strategies is not realistic from a practical perspective, although it may be of interest from an academic point of view. The following sections present the results for analysis of the physical and economic efficiencies of alternative risk management strategies with inclusion of tactical adjustments in response to climatic variability.

#### **9.4. Implication of including tactical adjustments in risk management strategies**

##### **9.4.1. The value of tactical responses and/or cost of variability**

As noted previously, most previous modelling studies on agricultural risk management has not included the possibility of sequential decision making in response to prevailing conditions as they unfold. From an academic perspective then, it is of interest to determine how much the inclusion of tactical responses is worth. The value of including tactical adjustment in risk management strategies and/or cost of variability can be calculated by obtaining the difference between the maximum expected profit ( $E_p$ ) with and without inclusion of the tactical adjustment— that is, subtracting the best combination without inclusion of tactical response at \$836.91 ha<sup>-1</sup> (3,16) as shown in Table 8-5 and the best combination with inclusion of tactical response at \$1172.95 ha<sup>-1</sup> (4,16,10) as shown in Table 8-6. Given the assumed prices and costs, the annual cost of variability and/or value of including tactical responses in risk management strategies designed for high performance dryland sheep systems in Canterbury region of New Zealand is therefore \$336.04 ha<sup>-1</sup>. The value of tactical response in risk management strategies and/or cost of variability represents 40.15% of the average GM. The increase in  $E_p$  is attributable to an increase in meat production which ranged between 30.16 kg ha<sup>-1</sup> for strategy 1 at 10 SR and 15.0% SML to 122.18 kg ha<sup>-1</sup> for strategy 4 at 16 SR and 10.0% SML. In addition to contributing to higher

farm profitability, the extra meat production represents an increase in physical efficiency when adjustments are included in the risk management strategies (that is— more meat is produced per unit area of the farm). The average increase in wool production due to incorporating tactical adjustments was small and was not considered to alter the change in  $E_p$  significantly. This was expected as tactical responses occurred post-shearing in this study; while shearing occurred pre-lambing, tactical adjustments were presumed to be triggered after lamb tailing.

Table 8-9 shows the percentage increase in GM for corresponding strategies 1-7 without/with inclusion of tactical responses in risk management at 10, 12, 14 and 16 SR. The differences represent the cost of failing to incorporate tactical adjustment to climatic variability in management. The difference ranged between 3.14% or \$15.30 ha<sup>-1</sup> for strategy 1 at 10 SR with trigger SML at 10.0% and 39.65% or \$316.06 ha<sup>-1</sup> for strategy 4 at 12 SR and trigger SML at 10.0% of the top 25.0 cm. The differences are mainly attributable to a combination of increased productivity during better than average pasture growing years (increased profit) and decreased losses during worse than average pasture growing years (decreased loss). This was consistent with the findings of Kingwell *et al.* (1993) who found that expected farm profit could be increased by over 20.0% through appropriate tactical adjustment of farm plans.

An additional benefit of including tactical responses to climatic variability in risk management strategies was a reduction in income variability or risk as shown in the difference that exist between the values of coefficients of variation for profit for strategies without/with inclusion of tactical adjustments. Table 8-10 shows the percentage decrease in coefficient of variation for the GM between corresponding strategies without/with inclusion of tactical responses to a drop in SML to 10.0, 12.5 and 15.0% in the top 25.0 cm soil at 10, 12, 14 and 16 SR. The decrease in GM variability between corresponding strategies was very large ranging between 19.74% and 67.38%. Results from analysis of variance of GM and risk showed that management strategies incorporating tactical responses to climatic variability had statistically significantly higher returns at \$703.42 ha<sup>-1</sup> compared to \$608.73 ha<sup>-1</sup> when ignored. Similarly, strategies incorporating tactical responses to climatic variability had statistically significantly lower risk of \$100.71 ha<sup>-1</sup> compared to \$173.18 ha<sup>-1</sup>.

By incorporating tactical responses in the evaluated risk management strategies, this study has not assumed a fixed calendar of events as many do and the model has thus adapted its management to the changing environment. Such responses result in benefits which can be quantified but would remain unaccounted for in a system that ignores an opportunity afforded

by the varying production environment.

### 9.5. The risk-efficient frontier

The risk-efficient frontier presented in Figure 8-6 can be used as a decision tool by producers to select where they wish to operate depending on how much return they wish to obtain versus how much risk they are willing to take. Hardaker *et al.* (1991) stressed the importance of addressing the diversity of farmers' preferences and risk attitudes. This concern is sufficiently addressed by defining a risk-efficient frontier which provides a means of partitioning decision strategies into efficient and dominated sets. Any individual farmer will find an optimal strategy among the efficient set. Hardaker *et al.* (1991) observed that the task of the analyst is to make the efficient set as small as possible without excluding from the set any strategies that would actually be preferred by an appreciable number of farmers in the target population.

Considering the risk-frontier obtained in this study for strategies without incorporation of tactical adjustment, strategy 3 at 16 SR would be the optimal choice for risk-indifferent producer, while strategy 7 at 10 SR (7, 10) would be the optimal choice for an extremely risk-averse producer. Where tactical adjustments to climatic variability are included in the risk management strategies, the optimal choices for risk-indifferent and extremely risk-averse producer would be strategy 4 at 16 SR and 10.0% SML (4, 16, 10) and strategy 7 at 10 SR and 15.0% SML (7, 10, 15) respectively. Most farmers are risk-averse according to Kingwell *et al.* (1993). However, risk-aversion does not mean that individuals are not willing to take risks; rather it means that individuals must be compensated for taking the risk and that the required compensation must increase as the risk and/or the levels of risk-aversion increase (Kay and Edwards, 1999). This emphasises the use of the risk-efficient frontier as a guide for producers on the risk-return trade-off rather than putting too much emphasis on producer's risk attitude.

Figures 8-6 shows the risk-efficient frontiers for strategies 1-7 at 10, 12, 14 and 16 SR without (A) and with (B) tactical adjustments to climatic variability. The frontiers show the best possible combinations of  $E_p$  and risk in relation to alternative management strategies. Clearly most of the strategies between the two sets differ which implies that failure to incorporate tactical adjustment in risk management is likely to change the choice of strategy and could lead to the choice of a sub-optimal strategy. Another observation is the larger number of strategies falling on the risk-frontier when tactical responses are included in risk management strategies giving a producer a bigger choice of efficient strategies from which to choose. Table 9-1 shows the number of strategies falling on the risk-frontier curves. Notably

there were more efficient combinations (13 compared to 8) when tactical responses were included in risk management strategies.

**Table 9.1:** A list of strategies with and without incorporating tactical responses in risk management falling on the risk-efficient frontier

Number of strategies	With (S, SR,SML)	Number of strategies	Without (S, SR)
1	7,10,15	1	7,10
2	2,10,15	2	3,10
3	3,10,15	3	5,10
4	5,10,15	4	2,12
5	2,12,15	5	5,14
6	3,12,15	6	4,14
7	6,16,15	7	2,14
8	6,14,15	8	3,16
9	2,14,15		
10	2,16,15		
11	3,16,12.5		
12	3,16,10		
13	4,16,10		

While there is a range of options falling on the risk-efficient frontier when tactical responses are included, the majority are those based on conventional pasture systems (strategies 1-4) rather than high quality pasture types (strategies 5-7). Also, as long as tactical responses are included, the options including cattle (strategies 2 and 4) are more efficient than those that do not, emphasising the point made earlier regarding the use of cattle as a flexibility option rather than a fixed production option. Also within strategies there is a general, but not absolute trend that as the stocking rate increases, implying a higher risk, more aggressive policy, trigger SML reduces, also reflecting a more aggressive stance. Compare trigger SML as stocking rates increase for strategies 2 and 4 in Table 9.1, for example. Only 3 (approximately 37.5%) strategies with cattle fell on risk-efficient frontier when tactical responses were ignored which increased to 7 (approximately 53.85%) when tactical responses were considered. Additionally, only 4 strategies with (1, 4, 7 and 8) and 2 without (1 and 5) emphasizing on pasture quality (more area devoted to legume pastures) fell on risk-efficient frontier.

In general, irrespective of a producer's risk attitude, it would not be rational to operate below any point on the risk-efficient frontier as that would imply getting less profit at the same level of risk or the same profit with greater risk.

## 9.6. Sensitivity of GM to meat and wool price changes

Results presented in Table 8-13 show that as prices varied the GM changed indicating that GM was sensitive to market risk (represented by the assumed price variations) and implying that price variability should be considered in determining how to respond to risk as its variation affects enterprise profitability. Pannell *et al.* (2000) observed that use of

sensitivity analysis to examine discrete key scenarios and in identifying break-even circumstances is a simple, but valuable method of incorporating risk in decision processes, both from the point of view of risk aversion and in tactical adjustments. These authors further noted that the techniques are unsophisticated and old, yet they provide the producer with an opportunity to discern the nature and potential impact of uncertainties in a way that promotes sensible management of risk. The prices used in the current simulation were real and therefore included all the variability due to market changes and climatic effects.

An important observation from the sensitivity results presented in Table 8-13, is that even where the multiplier applied was the same for all the levels of response(s) the change in GM differed implying that the effect of market risk varies depending on whether tactical adjustment are incorporated in risk management and also the level to which the farmer is willing to wait until implementing destocking actions (that is, the value of SML in this context). This is expected as the change is as a result of shift in supply and demand and subsequently prices. In the context of this study, this means more animals being sold in bad weather forecast and vice versa. Where panic selling occurs as a result of prospects of unfavourable weather (unfavourable to support enough pasture growth), more animals are taken to the market and supply outstrips demand which leads to a price fall as shown in Figure 8-3. However, based on the fact that risk attitudes differ amongst producers, the time at which they respond to the risk varies (represented in this study by the three trigger SML values) with a value of 10.0% (which is wilting point) representing producers who would be willing to hold on to their stock until the projected risk and/or its impact is more certain to occur at which point there still a possibility of getting rain and delaying destocking.

Results from the simple price change analysis shows that enterprise profitability was affected by the prevailing commodity prices.

### **9.7. Choice of trigger variable and its value**

Three main variables have been suggested as being important in making decisions on when to respond to climatic variability. They are soil moisture, meat and wool prices and pasture cover. In a way, the three are related and a strong relationship exists between soil moisture and grazed pasture cover. This is because pasture growth depends among other things on the moisture available (Peri *et al.*, 2005). Though pasture cover responds to pasture growth in relation to environmental variables such as moisture and nitrogen, its use as an indicator may be considered limited because it is also affected by some management practices as shown in this study. Furthermore, Johnson and Parsons (1985) showed that stocking rates not only affect livestock growth rates, but also pasture production. Therefore basing

destocking/sales decisions on pasture cover would be influenced by individual farmer's grazing management decisions making it subjective. It is, however, important to note that subjectivity was considered in deciding how much destocking to carry out through development of the severity index described in section 6.2.1.

While it is possible to set absolute values for pasture cover (e.g. 1200 kg ha<sup>-1</sup>) or soil moisture level (e.g. 12.5% moisture in top 25.0 cm soil), it would be difficult to set an absolute value for the market price at which farmers should react to bring feed demand and supply on the farm into balance. Furthermore, market price is responsive to climatic variability as previously shown in Figure 8-3. Based on the observations presented above, soil moisture level (SML) appears to be the most appropriate environmental variable to monitor.

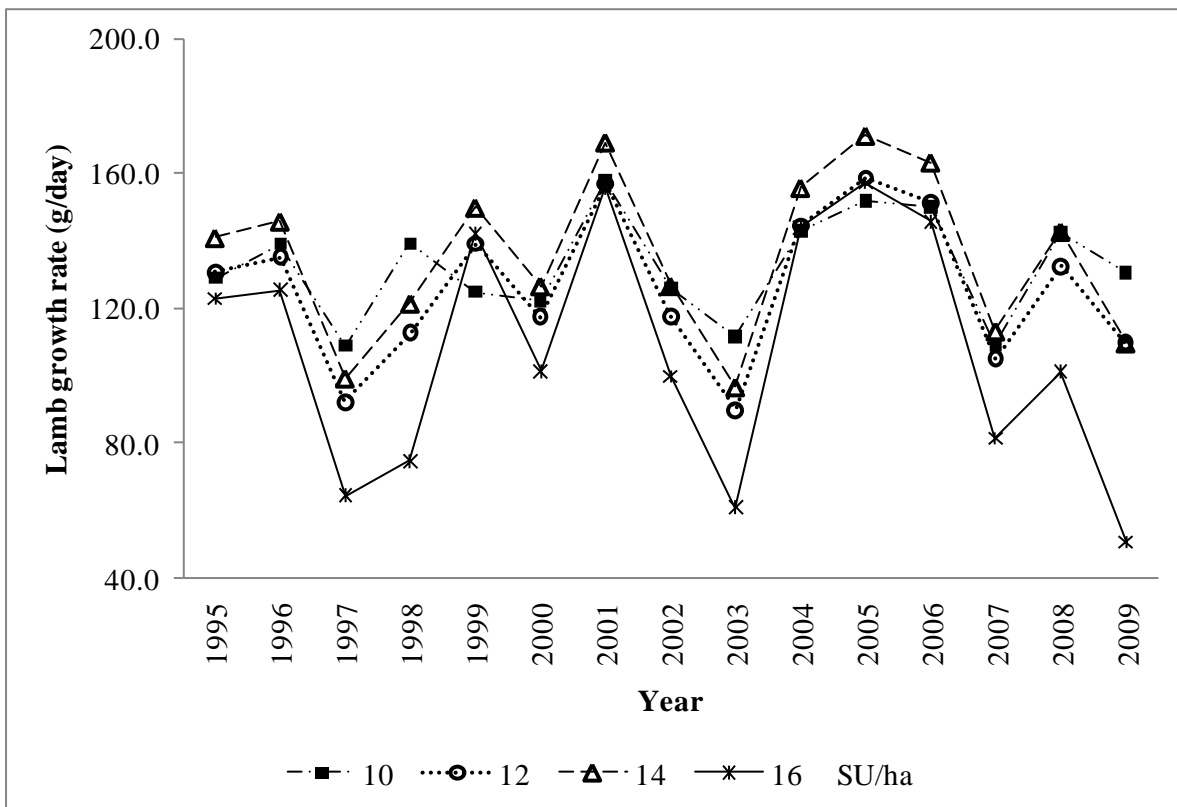
### **9.8. Factors contributing to increased productivity and profitability of alternative risk-efficient strategies**

This section presents a summary of key elements that contributed to increased productivity and profitability in alternative risk-efficient strategies in high performance dryland sheep production systems. They are broadly categorised as animal, pasture, and management related elements and closely relate to those in the SISST study described in Bywater *et al.* (2010). The strategies tested in this study were informed by the SISST study whose objective was to investigate and demonstrate key elements of high productivity sheep systems in dryland environments.

It is possible to simulate animals with different genetic makeup in Linfoam by varying relevant parameters. Breeding ewes utilised in model farms representing different strategies in this study were set to have low body weight and high fecundity (holding other factors affecting reproduction constant). Such ewes were considered to be highly efficient which was defined as the weight of lamb weaned per tonne of DM eaten or as kg of litter weaning weight per kg ewe LW at weaning (Bywater *et al.*, 2010). This was considered as a key element of high productivity in sheep systems in dryland environments as it was shown that the "smaller" ewes were 20.0% more efficient than the "large" ewes in a study carried out at Ashley Dene farm of Lincoln University (Rutherford *et al.*, 2003). In that study whose results were used in deciding on whether to use "small" or "large" ewes in the SISST research trial, data from well-recorded flocks was used to identify variation in ewe size and corresponding efficiency. The study found out that although "small" twin lamb-rearing ewes in the flock studied were 20 kg lighter at weaning than the "large" ewes, the "small" ewes had litter weight only 5 kg lower. The study further found out that none of the advantages to the large framed ewe in productivity were as great as the disadvantages in terms of LW and therefore relative stocking

rate. This means that output of weaning weight, wool weight and carcass weight (in system where lambs are finished) per ha was greater for small framed ewes than large framed ewes.

Strategy 2 run at 10, 12, 14 and 16 SR at 10.0% SML is used to demonstrate animal (lamb growth rate) and pasture (high quality through appropriate stocking) aspects contributing to increased productivity and profitability in alternative risk-efficient strategies in high performance dryland sheep production systems. Strategy 2 run at 14 SR represents the grass farm unit in the SISST. Figure 9-1 shows post-weaning lamb growth rates for years 1995-2009 for strategy 2 run at 10, 12, 14 and 16 SR at 10.0% SML.

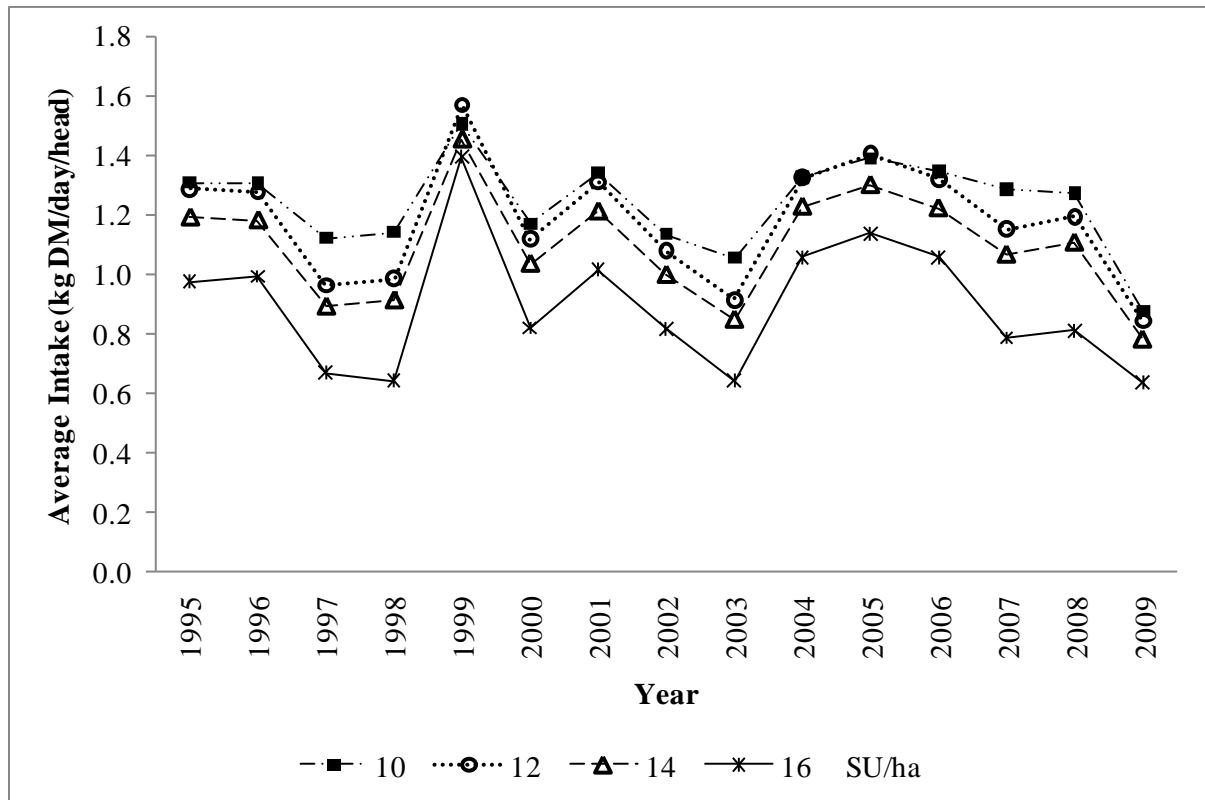


**Figure 9-1:** Lamb growth rates for years 1995-2009 for strategy 2 run at 10, 12, 14 and 16 SR at 10.0% SML

The post-weaning lamb growth rate differed amongst SRs with 16 SR trailing. Although it would be expected that strategies run at either 10 or 12 SR should result in higher growth rate compared to 14 SR in the production circumstances considered in this study, inferences deduced from plots in Figure 9-1 above imply that at those SRs pasture quality was most likely compromised as more was produced at key times than consumed, thus reducing quality and subsequently re-growth. Conversely, at 16 SR, more pasture was consumed relative to production reducing the amount of feed available to achieve high lamb growth rate. If too much grass is consumed in a paddock, there will be insufficient leaf remaining for the plant to achieve its potential re-growth due to lack of photosynthetic surface (Parson *et al.*, 1988), the reverse will result in formation of a basal thatch from plant dead material, stem

elongation and a decline in useful biomass to the animal (Stakelum and Dillon, 1990).

Figure 9-2 shows the corresponding annual average daily pasture intake for strategy 2 run at 10, 12, 14 and 16 SR at 10.0% SML. It is interesting to note that although pasture intake was higher when the model farm was run at 10 and 12 SRs compared to 14 SR, the resulting post-weaning lamb growth rates were lower. This can be attributed to higher pasture quality when the model farm was run at 14 SR as there was a favourable balance between production and consumption as described above.



**Figure 9-2:** Average daily pasture intake for strategy 2 run at 10, 12, 14 and 16 SR at 10.0% SML

As shown in Figures 9-1 and 2, high lamb growth rates and high pasture quality are key elements of high productivity sheep systems in dryland environments.

Another potential key aspect shown to increase productivity and profitability in high performance dryland sheep production systems is the identification of trigger values based on prevailing conditions and corresponding destocking response to ensure disposal of stock to best advantage. This thesis was focused on this area and has shown the best trigger to monitor in dryland systems is soil moisture level, with productivity and profitability differing over the proposed range of 15.0-10.0% moisture levels in the top 25.0 cm soil. Results in this thesis further showed that the more aggressive the stance in terms of stocking rate, the more aggressive the stance should be in terms of SML trigger values. More specific details on key elements of high productivity and profitability dryland sheep systems are available from Bywater *et al.* (2010) from which data the analysis carried out in this study was based.

## 9.9. Conclusions

Results obtained in this study illustrate that incorporating tactical responses to climatic variability in risk management policies in high performance dryland sheep systems provides benefits by increasing profits and reducing income variability. The study further provided information on alternative risk management strategies and accompanying tactical adjustments in response to climatic variability in dryland sheep systems irrespective of a producer's risk attitude. The results show that, independently of the assumed risk attitude of the producer, it is important to account for variability in a dynamic management model.

The findings of this study bring to light the fact that failure to incorporate tactical adjustments to climatic variability will result in the choice of a sub-optimal risk management strategy. This is in addition to reducing the number of potential efficient risk management strategies afforded to producers to choose from.

The results further add support to the hypothesis of Pannell *et al.* (1995) that benefits in decision analysis from accounting for tactical adjustment 'are often' if not usually, greater than the benefits of including farmer's risk attitude. Therefore, models which do not incorporate facilities for tactical responses ignore the fact that farmers in the real world respond to opportunities or threats occurring as a season progresses and information on uncertain events become known (Dorward, 1999), and may identify optimal strategies incorrectly (Kingwell *et al.*, 1993).

All strategies incorporating tactical responses were economically superior to those which did not. The extra income can be viewed as the cost to the farmer of basing choice regarding a management strategy on analysis that neglects the advantages afforded by tactical responses.

The plot of expected GM and risk (measured as the standard deviation of the profit) provides the most risk-efficient frontier from which producers can compare and choose risk management strategies that fit their production objective without losing the opportunity provided by tactically responding to 'better' or 'worse' than average pasture growing conditions. The risk efficient strategic/tactical combinations obtained in the current study are comparable with those reviewed in section 2.5, and to traditional approaches which has been shown to be risk efficient if combined with conservative destocking rules.

Market variability is an important source of risk and a simple price change analysis considered in this research has shown that management practices geared towards increasing enterprise profitability should consider seasonal prices and costs changes.

## 9.10. Recommendations for future research

Within the time and resource constraints that accompany any research activity, some simplifying assumptions are usually made to make the problem tractable. These often identify areas of future research. In this case, some aspects of the situation were ignored or included in the modelling framework in a relatively simple form which thus may lead to future research activities:

- To develop a mechanistic model of brassica growth to aid farmers with a tool that will assist in evaluating the economic and physical effect of specific crop husbandry treatments. The use of a thermal time based model to simulate growth and development of brassica crops was necessary in the current situation. Although results are not time or site specific, it does not account for extremes in environmental conditions or for variations in husbandry. For example, even though it would be expected that brassica crop growth in warm and humid places would be challenged by the favourable conditions provided to fungal diseases, basing production simply on Tt would predict high yield for such areas regardless of their management or disease prevention measures.
- To undertake field experiments designed to obtain missing parameter estimates necessary in describing the brassica growth using existing mechanistic pasture growth and productivity models
- To re-evaluate the results provided in this thesis in the light of environmental sustainability
- To re-evaluate the risk strategies with input costs and output prices as a part of the decision framework. This was not the objective of this study and the section describing simple price sensitivity analysis was meant to highlight the importance of considering price changes in risk management policies.

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## **Publications in the course of study**

- Bett, R.C., **Gicheha, M.G.**, Kosgey, I.S., Kahi, A.K., Peters, K.J. 2011. Economic values for disease resistance traits in the smallholder goat production systems. *Small Ruminant Research (in press)*.
- Gicheha M.G.**, Bett, C.R. 2010d. Increasing accuracy in estimation of economic values for resistance to gastrointestinal helminths in meat sheep. *Tropical Animal Health and Production*, **4**: 391-396.
- Gicheha M.G.**, Joyce, W.G., Bett, R.C. 2010c. Potential indices for calculating economic values for resistance to gastrointestinal helminths. *In: Proceedings of the 9<sup>th</sup> World Congress on Genetics Applied to Livestock Production*, 1-6 August, 2010, Leipzig, Germany.
- Peters, K.J., Bett, R.C., Kahi, A.K., Kosgey, I.S., **Gicheha, M.G.** 2010b. Comparison of economic values without and with risk for breeding objective traits derived from producer's preferences. *In: Proceedings of the 9<sup>th</sup> World Congress on Genetics Applied to Livestock Production*, 1-6 August, 2010, Leipzig, Germany.
- Gicheha, M. G.**, Kosgey, I.S. 2010a. Risk rated economic values for traits of meat sheep in smallholder production system in the tropics. *Driving livestock entrepreneurship towards attainment of food sufficiency and Kenyan Vision 2030, Proceedings of the Animal production Society of Kenya Regional Conference on Livestock Revolution*, 20–22 April 2010, Garissa, Kenya.