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The Modelling Alternative Dryland Sheep Systems

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Definitions

Flushing: The practice of increasing the nutritional level of ewes prior to mating in order to increase ovulation rate.

Scanning Percentage, Scanning Rate: The results of ultra-sound scanning of pregnant ewes usually around two months prior to lambing in order to determine the number of foetuses carried by the ewe.

Stock Unit (SU): A measure of the carrying capacity of land or the feed requirement of stock; a standard stock unit is defined as a 55 kg ewe weaning a single lamb and equates to approximately 4200-4500 MJ ME $year^{-1}$.

Terminal Sire: Rams, usually of a meat breed, mated to ewes to produce lambs destined for sale as meat rather than retained or sold as replacement stock.

Works: Slaughter facility, usually but not always, producing meat for export.

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Summary

On the east coast of New Zealand, sheep and beef cattle are increasingly confined to dry hills and un-irrigated flat land as land suitable for irrigation is converted to other uses. Dryland farming is subject to significant variability in temperature and particularly rainfall between and within years with the most important climate risk being the point at which soils dry out and pasture production ceases in late spring/summer.

Improving pasture and animal performance and, in particular, the consistency of productivity and profitability in the face of a highly variable climate is complicated. The challenge is to utilise the 3-5 month window of opportunity for production between August and the end of the year to best advantage and without compromising the ability to feed ewes well in late summer/autumn prior to mating.

Key variables in this context are high lamb growth rates in order to finish as many lambs as possible before the risk of dry conditions becomes too high, and flexibility to respond to the growing conditions as they unfold.

The objectives of this research were to investigate, and demonstrate, opportunities for improving dryland sheep systems through increased lamb output, high pasture quality and utilisation, and flexibility to respond to climate and feed conditions.

The research included a farm scale trial, adaptation of an existing sheep farm simulation model LincFarm (Cacho *et al.,* 1995; Finlayson *et al.*, 1995) to replicate the trial situation, development of an algorithm for optimising de-stocking interventions in response to dry conditions, and evaluation of the long term implications on productivity, profitability and risk of a range of policy options using the model.

This report provides a summary of the field trials, and describes extensions to and evaluation of the LincFarm sheep systems model and its use to analyse a combination of stock and pasture options at different stocking rates based on the field trial. Development of the de-stocking algorithm and evaluation of a range of risk responses are presented elsewhere (Gicheha *et al.*, 2013 a, b).

The field trials were based on two farm scale units at Lincoln University's Silverwood Farm near Hororata, a grass based unit of 87.8 ha and a legume based unit of 85.1 ha. The grass unit was stocked with a mixed age flock and trading cattle representing approximately 23 per cent of total stock units (SU) and the legume unit had the same mixed age ewe flock with additional older ewes mated early as a '1st cycle mob'. Both were stocked at 14 SU ha^{-1} which is approximately 5 SU ha^{-1} higher than the regional monitor farm.

With the exception of poor performance on the legume unit in the first full year of the trial, results confirmed that it is possible to maintain high pasture quality and utilisation on a range of pasture types in dryland conditions with a high stocking rate and that this can lead to high scanning percentages and high pre- and post-weaning lamb growth rates.

Monitoring soil moisture provided a relatively simple and cheap way of identifying when to respond to changes in climate and pasture conditions. While results from the legume unit were disappointing, results from the grass unit suggested that stocking at a high rate to maintain pasture

quality and animal performance as well as building in flexibilities to respond to climate and pasture conditions when required can both increase returns per ha and reduce the variability of returns from one year to the next in comparison to the regional monitor farm.

These are un-replicated results from only two years of trial with one management policy on each unit. In order to investigate a broader range of climate conditions and management policies at different stocking rates, an analysis has been undertaken using the sheep farm simulation model LincFarm.

The LincFarm model was previously parametised for perennial ryegrass, white and red clovers, tall fescue and chicory, and for sheep. The model needed to be extended to include species used in the trial including annual ryegrass, cocksfoot, lucerne, both summer and winter brassicas and growing cattle.

Reparametisation of the mechanistic pasture model in Lincfarm for annual ryegrass, cocksfoot and lucerne, and development of a germination and emergence routine are described. Statistics of fit for the model against data sets from the NZ Plant Breeders Assoc. and unpublished data from Lincoln indicate coefficients of determination in excess of 0.95.

A simple model of dry matter accumulation of brassicas based on thermal time units and soil moisture is developed and provided similarly good fits to data on the growth of kale, forage rape and pasja (leaf turnip).

A model of beef growth and composition developed at Davis in the US (the Davis Growth Model, DGM; Oltjen *et al.*, 1986) is reparametised for New Zealand conditions against data on growth of Angus x Hereford heifers at Lincoln. Statistics of fit are presented and were considered adequate for inclusion in LincFarm.

The extended model was then evaluated against data from the Silverwood trials and showed good fits for total pasture cover, growth of lucerne and 'switch' pastures (perennial clovers oversown with annual ryegrass), and drafting weights for cattle. Fits for the yield of kale were less good, especially in the first year of the trial when the yield of one kale variety in particular was very poor.

An analysis including 7 different combinations of stock and pasture mixes, each run at 4 stocking rates (SR = 10, 12, 14, 16 SU ha^{-1}) over 19 years with the first 4 years discarded, using a soil moisture trigger value of 10% in the top 25 cm of soil (the same as in the Silverwood trial) was then conducted using LincFarm. Results include the mean and standard deviation (SD) or coefficient of variation (CV) for pasture production, lambing percent, carcass meat production and wool production per ha, and the income and variable costs (gross margin, GM) per ha.

Generally as SR increased so did the mean and CV of production and returns. A plot of the mean GM against the SD of GM allows identification of the 'risk efficient frontier', those combinations of strategy and SR which are dominant in terms of risk vs return. These include lower return-lower risk combinations, higher risk-higher returns combinations and those that are intermediate.

The results indicate that those strategies which include high nutritive values pasture species such as legumes are risk efficient at the lower risk-lower returns end of the frontier, at stocking rates which are similar to those current on the Canterbury Plains. Risk efficient strategies at the intermediate risk and high risk-high return end of the frontier all involve conventional pasture supply systems (ryegrass-white clover) at progressively higher stocking rates, suggesting that with these pasture types, high stocking rates are required to maintain pasture quality and obtain high returns.

All of the risk efficient combinations include some flexible stock class in the form of either trading cattle or a buffer mob of ewes to allow a rapid response when climate conditions change. In the analysis responses were initiated when soil moisture dropped to 10 per cent in the top 25 cm. Other trigger variables or values would be possible.

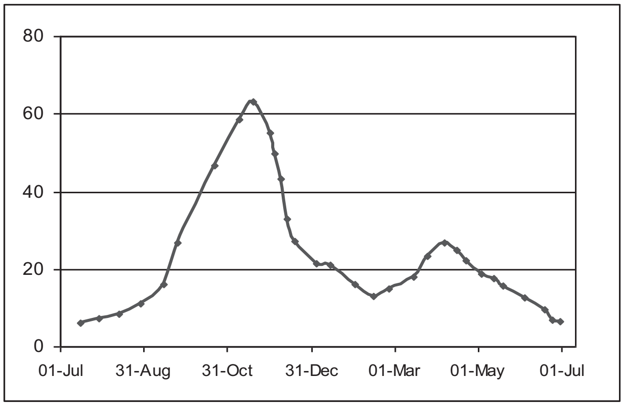
Chapter 1
Introduction

Over the last decade, much of the irrigable land in the South Island of New Zealand has been converted to dairy and cropping. Even on dryland farms, dairy grazers have displaced sheep and beef stock units and as a consequence, sheep and beef cattle are increasingly being confined to dry hill country and some un-irrigated plains.

Dryland farming on the east coast of both main islands is subject to significant climate variability. Rainfall is the main climatic factor constraining pasture growth, with spring and summer rainfall accounting for 60 per cent of the variation in annual pasture production (Radcliffe & Baars, 1987). Baars & Waller (1979) identified both rainfall and temperature as influencing pasture production, with temperature playing an important role in pasture growth in winter and early spring.

On the Canterbury Plains, for example, winters are normally cool and wet and summers warm and dry - but not always so. Spring and autumn can either be wet or dry, warm or cool. A *typical* pattern of dryland pasture growth is shown in Figure 1.1. There is low growth during winter because soil temperatures are too low even though there may be sufficient moisture. Growth accelerates 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 lack of rainfall in summer (any time from October onwards). A resurgence of growth may occur with autumn rains in April/May followed by a return to low growth again as temperatures drop from June onwards.

Figure 1.1: Three year average growth rate (July-June) of Ryegrass:White clover swards (kg DM ha^{-1}day^{-1}) at Hororata in Mid- Canterbury.

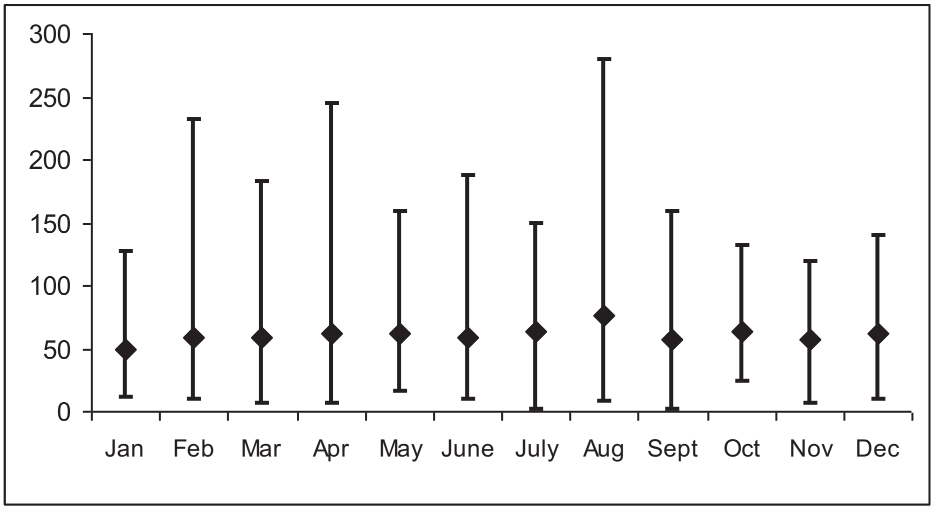


(Bywater *et al.*, 2010)

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. There have been some years when there was no rain for 18 months; the 1988-89 drought for example is estimated to have cost farmers on the east coast of the North Island $240 million in reduced income and the total region $1000 million (Nield, 1990).

Although Figure 1.1 shows a typical pattern of growth, an analysis of 30 years of data from the NIWA virtual climate station network (Tait *et al.*, 2006) for Hororata in mid Canterbury New Zealand (Latitude: -43.559962, Longitude: 171.84911) shows that in fact average monthly rainfall does not vary very much between months (Figure 1.2). However, the variability across years is extremely large, with the highest standard deviation and range in August and the lowest in October and November. In all months of the year, the range is greater than the mean.

Figure 1.2: Mean and Range in Monthly Rainfall over 30 years at Hororata, Mid-Canterbury from the NIWA Virtual Climate Station Network



Despite the climate patterns, Avery *et al.* (2008) suggest that pasture growth is reasonably reliable through winter and spring (the variability is less than the mean) until November but then becomes much less predictable (variability far exceeds the mean). The possibility of rainfall decreasing during late spring and summer to a point where grass growth ceases represents a major risk in dryland farming.

Seasonality in herbage production drives sheep production with ewes normally mated in autumn to match lambing with the spring pasture flush. Lambs are ready for slaughter any time throughout summer and autumn (Morris *et al.,* 1993). As there is generally adequate high quality grass growth to support production from mid August through to sometime around November, this provides a 'window of opportunity' for production which is highly variable in length. Over late spring and summer, farmers are in a high risk period when conditions can dry out quickly. Lambs which are not sold before then are at risk of growing much more slowly because of lower pasture availability and/or quality, extending the production period and requiring more feed in total. Variable rainfall patterns in late summer can make it difficult to provide adequate feed *in situ* to increase ewe live weights prior to mating to ensure high lambing percentages in the following season. If lambs are retained, grow slowly over summer, are held too long and start to compete with ewes for the best available feed, this may exacerbate the situation and jeopardise performance in the following year (Avery *et al.*, 2008).

Improving pasture and animal performance in dryland farming systems is therefore complex because of the need to balance the nutritional requirement of different classes of livestock with a feed supply that fluctuates in quantity and quality within and between years (Finlayson *et al.*, 1995). In most grazing sheep production enterprises, management interventions geared towards maximizing productivity and profitability generally target increased lamb growth rates, increased stocking rate (SU ha^{-1}) and/or increased lambing percentage (Diaz-Solis *et al.,* 2006). However, increasing either of the latter two inevitably results in higher demand for feed and, where climate is a highly variable limiting factor, higher risk.

Walker (1995) and Diaz-Solis *et al.* (2003, 2006) suggest that setting stocking rate has been the dominant risk management decision in temperate grazing livestock systems. Traditionally, dryland livestock farmers in New Zealand have taken a conservative approach by keeping stocking rates quite low, around 9 SU ha^{-1} in Canterbury/Marlborough (MAF, 2010). However, managing the within and between season variability by short term manipulation of feed supply and/or animal feed requirement offers opportunities for improvements in such systems (Gray *et al.*, 2008; Webby & Bywater, 2007).

The challenge is how best to utilise the 3-5 month window of opportunity for production described above to optimise productivity and profitability and to do so consistently from one year to the next despite highly variable rainfall patterns and without compromising the ability to feed ewes well in autumn. Key variables in this context are lamb growth rate in order to finish as many lambs as possible before the high risk period; and flexibility to respond quickly to the situation if and when condition become dry.

Several previous studies have shown that feed quality is a major determinant of both lamb growth rate and reproductive performance (Waghorn & Clark, 2004) and that use of alternative pasture species has the potential to improve the productivity and/or profitability of hill country (Grigg *et al*., 2008; Korte & Rhodes, 1993) and flatland farms (Fraser *et al.,* 1999). Grigg *et al*. (2008) showed the advantage of managing for increased subterranean clover content on hill country, Avery *et al*. (2008) demonstrated the benefits of a high proportion of lucerne, and on dryland on the plains, Fraser *et al.* (1999) investigated use of a variety of high nutritive value species, including chicory and red clover. The downside of using these species is often limited feed supply over winter which can be addressed by including forage crops, forage cereals or annual ryegrass, but at a cost. Nevertheless, financial benefits of changing from a conventional feed supply system can be dramatic (Avery *et al*., 2008). Studies that placed emphasis on high feed quality, particularly before weaning, without using alternative pasture species are reported by Kinnell (1993) and Gray *et al*. (2008).

The objectives of this research were to investigate and demonstrate opportunities for improving dryland sheep systems by increasing productivity and profitability through increased lamb output with high pasture quality and utilisation, and by managing climatic variability by including flexibility to respond to climate and feed conditions as they develop. The study included a farm scale trial, development of an algorithm for optimising de-stocking and sales in light of prevailing conditions, adaptation of an existing sheep farm simulation model (LincFarm) to replicate the trial situation, and evaluation of the long term implications on productivity, profitability and risk of a range of policy options using the model.

Results of the farm trials are reported in Bywater *et al.* (2010, 2011 a, b) and development of the de-stocking algorithm is presented by Gicheha *et al.* (2013 a). This report describes extensions to, and evaluation of, the LincFarm model and its use to analyse a combination of stock and pasture options at different stocking rates based on the field trials. A summary of the trial is presented as background to the modelling. Further analysis of the long term implications of different risk responses and trigger values is presented in Gicheha *et al.* (2013 b).

Chapter 2
Field Trials

The field trial was carried out to investigate and demonstrate key aspects of high performance sheep systems in dryland environments. Key considerations were to develop feed supply systems on a farm scale that would deliver high feed quality throughout the growing season leading to high lamb growth rates, early sale of lambs and the opportunity to feed ewes well before mating to obtain high scanning rates the following year; and inclusion of flexible management strategies to allow rapid de-stocking as soon as conditions became dry to reduce variability of returns. Previous research has shown that risk (variability of returns) normally increases as returns (and stocking rates) increase (Cacho & Bywater, 1994; Hardaker *et al.*, 1997).

In addition, the field trials were designed to investigate risk response indicators and provide base-line data for subsequent analysis of alternative policy options and risk responses using the simulation model, LincFarm. Details of the trial and its results are provided in Bywater *et al.* (2010, 2011 a, b); a summary is given here as background to the modelling.

2.1 Materials and methods

Two different approaches to maintaining high pasture quality and utilisation were investigated with non-replicated farm-scale trial units established at Hororata, mid-Canterbury: an intensively grazed conventional grass-based unit of 87.8 ha, and a high legume-content unit of 85.1 ha. Each unit had 16 paddocks, stocked at a target of 14 SU ha^{-1}, which is 5 SU ha^{-1} higher than the regional monitor farm (MAF, 2010). The first year of the trial in 2007/08 was used to bring data collection procedures and pasture and stock management into line with the trial protocol. Data collection was then carried out for two years, 2008/09 and 2009/10.

The grass unit included 13 paddocks of predominantly grass-based pasture (approximately 81 per cent of the unit); one paddock of lucerne (8 per cent of the unit); and two paddocks in a pasture-renewal rotation (11 per cent of the unit) including winter kale, followed by barley for silage and then a perennial grass mix in one paddock, and leaf turnip under-sown with a perennial grass mix in the other. Eight of the grass pastures were established ryegrass:clover pastures, two of which also contained cocksfoot and two tall fescue. Two older, brown top-dominant pastures were renewed through the above sequence in 2007/08 and two out of three Bareno brome pastures were renewed in 2008/09, all going into Alto ryegrass with white and red clover.

The underlying philosophy on this unit was that with a relatively high stocking rate, pasture utilisation would be high and pastures would be maintained in an actively growing state, ensuring a predominance of green leaf, minimum seed head development and a low proportion of dead material, and thus high feed quality (Litherland & Lambert, 2007).

On the legume unit there were four paddocks of predominantly grass-based pasture (30 per cent of the unit), five paddocks of ‘switch’ pastures (30 per cent of the unit) which are annual and perennial clovers over-sown with annual ryegrass each autumn (Nicol *et al*., 2010); five paddocks of lucerne (29 per cent of the unit); and two paddocks in a similar pasture-renewal sequence to the grass unit (11 per cent of the unit), except that forage rape was used instead of leaf turnip. The grass pastures included two established ryegrass:clover pastures and two of Bareno:clover which were renewed in 2007/08 and 2008/09 respectively, also going into the Alto ryegrass:clover mix. The five switch pastures were established at the start of the trial in 2007. In 2009/10, pastures on this unit changed to five paddocks of grass-based pasture and four paddocks of lucerne through the renewal programme.

The philosophy on this unit was that legumes provide high nutritive value feeds and retain their quality for longer than grasses if left un-grazed (Hyslop *et al.*, 2000) so that control of pastures is less critical. Forage rape was included in the renewal sequence to provide flushing feed for ewes at a time when switch pastures had recently been over-drilled with annual ryegrass and were unavailable for grazing.

Stock included a mixed age flock and 18 month-old trading cattle (23 per cent of total SU) on the grass unit and a mixed aged flock with additional older ewes on the legume unit. The main sheep breed was Coopworths from Lincoln University's Ashley Dene breeding flock (Nsoso *et al*., 1999), mated to terminal sires.

With a high stocking rate to maintain pasture quality, the risks and consequences of running out of feed when conditions become dry are high, making it more important to build in flexibilities to reduce stocking rate quickly when required. Cattle were purchased in May and sold any time after October according to feed conditions. Older ewes were lambed on 20 August (grass unit) or 13 August (legume unit), 3 and 4 weeks before the main mob respectively ('1st cycle' ewes), allowing early weaning, sale of lambs and culling of ewes if required (7 per cent and 20 per cent of SU on the grass and legume units, respectively). Main mob ewes were lambed on 6 September on both units with lambs weaned at 25 kg, or earlier if conditions became dry. Ewes were set stocked on individual paddocks one week before the start of lambing until weaning except for ewes on switch pastures. Pasture mass had diminished quickly following set stocking of these pastures in 2007/08 so they were subsequently rotationally grazed from before lambing to weaning. Store lambs were sold at weaning based on projected feed availability at the time. The lucerne and leaf turnip paddocks on the grass unit and two lucerne paddocks on the legume unit were targeted for lamb finishing, but were also available for ewes if required. Home grown or purchased silage or balage was used as a last resort to fill feed supply deficits.

Soil moisture readings were taken at weekly intervals from August to December and at fortnightly intervals for the rest of the year to 25, 50, and 75 cm soil depth in three paddocks on each trial unit. Pasture cover was assessed on all paddocks on the same schedule using a plate meter calibrated to the different pasture types every three months. Four grazing exclusion cages were placed in each of 12 paddocks, two each of the main pasture types. Two cages in each of these paddocks were cut every two weeks to 2 cm to estimate pasture growth rates giving a 28 day cutting interval for each cage. Pasture samples were taken from the same paddocks at 6 weekly intervals, cut to 2 cm and sub-sampled for herbage quality analysis using near infrared spectroscopy and dissection into botanical species components.

Five groups of either 30 or 40 ewes on the grass unit and three on the legume unit were weighed monthly from weaning to one month before lambing and fortnightly with their lambs from 6 weeks after lambing to weaning. These groups were lambed onto the same paddocks in which growth rates were estimated and samples collected for quality and composition analysis. Ewes were laproscoped for ovulation rate five days before mating, and ultrasound scanned to determine pregnancy rank in June. Further details of measurements and management are provided in Bywater *et al.* (2010).

Variables initially investigated as indicators of the need to de-stock were soil moisture, pasture growth rate, and average farm cover. To be effective, de-stocking decisions need to be implemented quickly, allowing for any marketing delays which are usually 7-10 days, so as to pre-empt market responses to dry conditions, such as difficulty in obtaining space at the meat works and reduced price of store stock (Gicheha, 2011). Under the fortnightly pasture sampling regime in this trial, pasture growth rate information was not available soon enough to be useful. Also, pasture covers did not vary sufficiently to serve as a meaningful indicator. On the other hand, soil moisture levels to 25 cm depth (SML_{25}) were read and available weekly and provided a clear indication of changes in growing conditions. A value of 10 per cent SML_{25} was used as the trigger to begin de-stocking as this approximates the point at which grass growth stops (N. Smith, Lincoln University, pers. comm., 2007). A de-stocking priority list was defined for each unit, depending on sales to date and whether weaning had occurred. Trading cattle and cull ewes were generally sold first, followed by store lambs, prime lambs, and then capital stock.

2.2 Results

Results of the trial are summarised below and are presented in greater detail in Bywater *et al.* (2010, 2011 a, b).

There was no difference between the two units in total annual pasture production calculated as a rolling three-period average over three years. Production was 10,414 kg DM ha^{-1} $year^{-1}$ on the grass unit and 10,336 kg DM ha^{-1} $year^{-1}$ on the legume unit. With the high stocking rate, pasture cover was maintained at a relatively low level and did not vary much during the year, despite large variations in pasture growth rate and animal demand. Farm cover averaged 982.9 kg DM ha^{-1} ± 219.2 kg DM ha^{-1} (standard deviation) on the grass unit and 1193.9 ± 250.8 kg DM ha^{-1} on the legume unit over the last two years of the trial.

The low pasture covers suggest that there was a good balance between feed supply and demand and that pasture utilisation was high. Based on the annual average pasture growth during the trial described above, and the total feed requirement of stock calculated from stock numbers and average performance recorded over the last two years of the trial using standard equations (AFRC, 1993), average pasture utilisation was estimated to be 71.7 per cent on the grass unit and 74.3 per cent on the legume unit.

The balance between feed demand and supply was close on the grass unit except in peak growth periods in spring and autumn but on the legume unit, there was a feed supply deficit in December and another in March (Bywater *et al*., 2011 a). The deficit in December could be relatively easily managed through stock sales, one of the response variables included in the trial. The March deficit was less easy to manage. This arose because ‘switch’ pastures on the legume unit were oversown with annual ryegrass in February/March and were therefore not available for grazing at this time; and because the legume unit was stocked entirely with sheep which increased feed demand for flushing in March compared with the grass unit where nearly a quarter of the SU were cattle, sold earlier in the season.

A key consideration in the trial was maintaining high pasture quality throughout the growing season with a target of 11.5 MJ metabolisable energy (ME)/kg DM. Average pasture quality is shown in Table 2.1. In 2008/09, ME averaged 11.6 and 11.5 MJ/kg DM on the grass and legume units respectively from April to October and then dropped when conditions became dry. Climate conditions in 2008/09 were such that soil moisture levels dropped to around 10 per cent by volume in the first week in November and did not increase again until February. In contrast, soil moisture levels remained above 20 per cent throughout the 2009/10 season. This is reflected in the pasture quality with average ME levels from April to the last reading in January of 11.6 and 11.4 MJ/kg DM on the grass and legume units, respectively. None of these differences were significant.

Table 2.1: Average pasture quality (MJ ME/kg DM) on the grass and legume units in 2008/09 and 2009/10

2008/09	17/04	12/05	11/06	7/07	4/08	16/09	31/10	8/12	19/01
Grass	11.4	11.8	12.3	11.4	11.5	11.2	11.4	10.0	10.1
Legume	11.1	11.4	12.1	11.4	11.7	11.8	11.3	9.3	10.4
2009/10	3/03	14/04	11/06	7/07	4/08	28/09	31/10	18/11	26/01
Grass	10.5	11.7	12.3	11.2	11.6	11.3	11.6	11.6	11.1
Legume	10.7	11.9	12.1	11.6	11.9	11.3	11.5	12.0	9.1

With pasture quality at or close to target, animal performance was also close to or above target. Targets for reproduction performance were to achieve 175 per cent scanning and 145 per cent survival-to-sale. Scanning percentages were close to or above target on both units but survival-to-sale was not (Table 2.2). Death rates of both ewes and lambs were higher than expected. Ewe deaths were 6.4 per cent and 8.1 per cent in 2008/09 and 7.3 per cent and 6.5 per cent in 2009/10 on the grass and legume units, respectively. Lamb losses between scanning and sale were very high, particularly on the legume unit in 2008/09. Bad weather in late August 2008 caused a number of ewe and lamb deaths, and a confirmed outbreak of *Salmonella Brandenburg* on both units in 2009/10 contributed to the high losses but may not be sufficient to explain them completely. Nevertheless, the losses resulted in lower than expected lamb sales particularly on the legume unit in 2008/09.

Table 2.2: Lambing percentage at scanning and survival to sale on the grass and legume units in 2008/09 and 2009/10

		2008/09		2009/10	
		Grass	Legume	Grass	Legume
Scanning%	1st cycle			176	171
	Main mob			177	179
	Overall	184	171	177	177
Sold/ewe scanned		127	106	139	136

Pre-weaning growth rates of single and twin lambs (Table 2.3) compare well with those observed in previous studies at high stocking rates on dryland (Ates *et al.*, 2006, 2008). They are much higher than the average pre-weaning growth rate of 221 g day^{-1} on 15 summer-dry farms throughout the South Island surveyed by Everest and Scales (1983). Analysis of variance of growth rate data available on 658 lambs over the two years using a restricted maximum likelihood model (Gilmore *et al.*, 2009) shows an overall mean and standard error of 304 ± 12 g day^{-1}. While there were significant differences due to litter size (singles, twins and triplets $P<0.001$), mob (first cycle and main mob, $P<0.05$), and year ($P<0.01$), there was no difference between the two units.

Post-weaning growth rate data were also available on 120 lambs. However, stock disposal policies at weaning included sale of lambs which had reached drafting weight and sale as stores of those which could not be finished on the assessed pasture available at that time. In other words the largest and smallest animals are not included in the post-weaning data which therefore should be treated with some caution. Average post-weaning growth rate was 139 ± 32 g day^{-1} with significant differences attributable to litter size, mob and year. Again this is much higher than the average post-weaning growth rate on summer-dry farms of 75 g day^{-1} found by Everest and Scales (1983).

Table 2.3: Mean and standard error of pre-weaning growth rates of lambs on the grass and legume units in 2008/09 and 2009/10

		2008-09		2009-10	
		Grass	Legume	Grass	Legume
1st Cycle	Singles	353.8 ± 16.0	290.1 ± 7.0	354.4 ± 20.5	296.9 ± 43.3
	Twins	301.6 ± 9.5	329.9 ±11.2	294.9 ± 19.4	188.4 ± 30.8
	Triplets	295.3 ± 38.7	226.5 ± 31.2	263.4 ± 14.9	236.0 ± 21.9
Main Mob	Singles	359.8 ± 13.0	356.1 ± 16.8	365.4 ± 10.9	337.9 ± 12.9
	Twins	302.1 ± 4.1	309.9 ± 7.5	314.3 ± 5.2	272.0 ± 5.2
	Triplets	239.4 ± 14.3	318.4 ± 19.9	270.1 ± 10.6	191.2 ± 17.5

Taking both pre-and post-weaning growth rates into account, average lamb growth rates from birth to sale over both years and both units was 295 ± 3 g day^{-1}, slightly lower than the target of 300 g day^{-1}.

In summary, the trial confirmed that it is possible to maintain high pasture quality on a range of pasture types including conventional ryegrass:clover pastures with a high stocking rate on dryland farms, and that this will lead to high scanning percentages and high pre-and post-weaning lamb growth rates.

2.3 Climate-risk responses

As noted, SML_{25} dropped to 10 per cent in the first week of November 2008 which triggered the decision to begin de-stocking as rapidly as possible subject to availability of killing space. Weaning of both first cycle and main mob lambs was completed before the end of the month with drafts of lambs and first cycle cull ewes going to the export works. All cattle were sold by 24 November. The remaining feed supply was assessed and light lambs which could not be finished were sold store in early December and any remaining cull ewes were sold over December and January as space became available.

In contrast in 2009/10, SML_{25} stayed above 20 per cent throughout the season and consequently, all weaning and sales were determined on target weights. Two drafts of lambs were taken before weaning the first cycle mob at the end of November; main mob lambs were weaned on 3 and 12 December on the grass and legume units respectively, with cattle sold in January, cull ewes in February, and lambs sales through to mid-March.

Because of the rainfall patterns in 2008/09, pasture growth rates decreased early and a high proportion of lambs were sold as stores. At weaning in 2008 there was little feed available on the legume unit in particular, primarily because of very poor performance of the lucerne paddocks which were old pastures. This resulted in a much higher proportion of lambs being sold early as stores on the legume compared to the grass unit; only 26.5 per cent and 68.0 per cent of lambs from the legume and grass units, respectively, were sold to the export market in 2008/09 whereas in 2009/10, 73.8 per cent and 76.0 per cent went to the export meat works from these units. Thus, the high lamb wastage rate in 2008/09 was compounded by poor finishing on the legume unit.

The dry conditions lasted until February 2009 and had the potential to cause a significant feed deficit that could have restricted ewe intake prior to mating, potentially leading to a lower lambing percentage in the following season. The flexibility and risk management responses on both units worked well in this situation with essentially all stock sales completed within three-and-a-half weeks of reaching the trigger point of 10 per cent SML_{25} (except for some cull ewes which took longer to move off farm). Both came through the dry spell with no real difference in pasture covers between the two years – in fact covers between November and February on the legume unit were slightly higher in 2008/09. Also pregnancy scanning percentages were similar in both years (Table 2.2). Unfortunately because of the high lamb wastage and failure of the lucerne on the legume unit, this did not translate into high production and profitability for the season on that unit. 2009/10 was a much more favourable season and all stock were held on both trial units for longer.

The main objective of risk management responses is to reduce the variability in performance and profit between years by maximising performance in good years and minimising losses in poor years. Selected financial performance indicators for the two units in 2008/09 and 2009/10 from Bywater *et al.* (2011 a) are shown in Table 2.4 compared with the Canterbury/Marlborough Breeding Sheep and Beef Monitor Farm (MAF, 2010). Despite the much higher stocking rate on the trial units, the lambing percentage to sale is similar to that on the monitor farm except for the 2008/09 season on the legume unit as discussed above. Net income, gross margin and surplus after overheads per ha are significantly higher on the trial units, again except for the legume unit in 2008/09. Per SU, net income is higher on the monitor farm as might be expected with a much lower stocking rate, but with higher direct costs per SU, gross margin and surplus per SU are slightly higher on the grass unit than the monitor farm, but slightly lower on the legume unit especially in 2008/09.

Table 2.4: Comparison of key financial indicators on the grass and legume units with the Canterbury/ Marlborough Monitor Farm (MAF, 2010) from Bywater *et al.* (2011 a)

		Grass Unit			Legume Unit			MAF Monitor Farm		
Effective area (ha)		87.8			85.1			469		
		2008-09	2009-10	Diff %	2008-09	2009-10	Diff %	2008-09	2009-10	Diff %
Total Stock units		1231	1172	-4.8	1205	1223	1.5	4096	4125	0.7
	SU ha^{-1}	14.0	13.3	-4.8	13.7	13.9	1.5	8.7	8.8	0.7
Lambing % to sale		126.5	139.3	10.1	105.9	136.0	28.4	125.0	138.0	10.4
		$	$		$	$		$	$	
Net Income[1]	ha^{-1}	1,211	1,170	-3.3	898	1083	20.7	866	965	11.5
	SU^{-1}	86.34	87.65	1.5	63.42	75.39	18.9	99.13	109.77	10.7
Direct Costs[2]	ha^{-1}	351	357	1.6	492	481	-2.1	375	436	16.2
	SU^{-1}	25.07	26.74	6.7	34.74	33.51	-3.5	46.80	49.56	5.9
Gross Margin	ha^{-1}	859	813	-5.4	406	602	48.2	491	530	7.9
	SU^{-1}	61.27	60.91	-0.6	28.68	41.88	46.0	52.32	60.20	15.1
Overheads[3]	ha^{-1}	72	61	-14.7	72	61	-14.7	80	72.44	-9.1
Surplus[4]	ha^{-1}	787	752	-4.5	334	541	61.7	411	457	11.2
	SU^{-1}	55.51	56.33	1.5	23.62	37.62	59.3	42.38	51.97	22.6

[1] Includes sale of culls and wool and cost of replacements
[2] Does not include labour
[3] Farm overheads pro-rated ha^{-1} for the grass and legume units; does not include interest costs
[4] Does not include labour, wages of management or interest charges

The difference between years in all financial indicators except for overhead charges is much smaller on the grass unit than on the monitor farm, suggesting that the ability to respond rapidly to varying growing conditions has the potential to reduce year to year variability in farm financial results, i.e. reduce risk. The same is not true of the legume unit where poor performance in 2008/09 resulted in a much larger difference between years simply because problems encountered during that season were not repeated the following year. This reinforces the importance of being able to finish lambs quickly in this environment, making it easier to deal with dry conditions if and when they arise.

Overall, the management strategies used in the trial were successful in maintaining pasture quality and animal performance at or close to target. Monitoring soil moisture provided a relatively simple and inexpensive way to identify a trigger for initiating tactical responses to changes in climate and pasture condition. While results from the legume unit were disappointing, they were influenced by factors which were not directly related to the risk management policies being evaluated. Results from the grass unit on the other hand suggest that building in flexibilities to deal with climate risk and responding to low SML_{25} can reduce variability in financial performance. However, this must be qualified by the fact that these were un-replicated trial units and it was not possible to consider different combinations of pastures and stock, different SML_{25} trigger levels or compare results over additional years with different weather patterns.

Chapter 3
The LincFarm Model

To investigate a range of pasture and stock policy combinations over a range of climate situations, a simulation analysis has been undertaken using the sheep farm simulation model, LincFarm (Cacho *et al.,* 1995; Finlayson *et al.*, 1995). This has been combined with a de-stocking and marketing algorithm developed by Gicheha *et al.* (2013 a) to simulate tactical interventions in response to changes in climatic conditions and feed supply in dryland grazing systems.

LincFarm is designed to evaluate alternative strategies for managing pastoral sheep systems. It has the facility to subdivide the farm into paddocks, allocated to blocks, in which different animal, pasture and management parameters can be applied. Animals are grouped into mobs, each with different management. It has the capacity to run an analysis for as many years as suitable weather data are available, with the state of the system carried forward from one year to the next.

LincFarm includes a mechanistic animal model described in Finlayson *et al.* (1995), a plant model described in Bywater *et al.* (1999), and a calendar of management events which schedules interventions such as purchases and sales, mating, shearing, drafting, etc and which controls the operation of the animals/mobs and paddocks/blocks (Cacho *et al.*, 1995). The management calendar includes a limited number of conditional decisions, meaning 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 needed to be expanded to include tactical marketing and destocking interventions in response to climatic variability, the fact that this is possible is essential for the analysis to be undertaken.

LincFarm has both front- and back-end programmes used to prepare input files and produce output reports respectively. Input data files define the farm, pasture and animal parameters, management, and experimental treatments to be simulated. There is flexibility to determine the output from the model, which allows a detailed analysis of the reasons behind an improved enterprise performance where required.

Prior to the analysis reported here, the model was parameterised for perennial ryegrass, white and red clovers, tall fescue and chicory, and for sheep. In the trial, pasture and stock types included annual ryegrass, cocksfoot, lucerne, both summer and winter forage Brassicas, and growing cattle. Thus there was a need to extend LincFarm to parameterise the pasture model for three additional pasture species, incorporate a crop model for Brassicas, and include a model of beef growth and composition. Following their inclusion, the revised LincFarm model was then evaluated against data obtained from the trial (Bywater *et al.*, 2010).

3.1 Setting parameters of a mechanistic pasture growth model

The mechanistic pasture growth model included in LincFarm (Bywater *et al.*, 1999) is based on the methodology described by Woodward (1997, 1998). The main advantage of this methodology compared to other more theoretical models is that it 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. The model is separated into five growth sub-models (photosynthesis, growth, reproduction, specific leaf area and assimilate partitioning), two site dependent sub-models (radiation and soil moisture) which are run once per day per site and two site and growth interaction sub-models (water stress and light capture).

The model is specified in two forms, one which represents the above ground canopy and is used for grasses and some clovers (Bywater *et al.*, 1999) and one which includes a root component used for some legumes and herbs such as red clover and chicory (Bywater *et al.*, 2000). Annual ryegrass and cocksfoot were specified using the first version of the model representing above ground components only and requiring a total of 45 parameters, while the second version including the root sub-model was used for lucerne requiring an additional 9 parameters.

Peri *et al.* (2005) suggest that in related species such as grasses, differences in parameters controlling response to the main environmental variables, rather than the entire parameter set describing the plant, influence net leaf photosynthesis and subsequent productivity in plant growth simulation models. For annual ryegrass and cocksfoot in ambient $[CO]_2$ conditions, the main determinants of growth are likely to be temperature (Baars & Waller, 1979), water (Radcliffe & Baars, 1987; Moloney, 1991; Barker *et al.,* 1993) and nitrogen status (Donohue *et al.,* 1981; Moloney *et al.,* 1993; Peri *et al.,* 2002). A search of the literature allowed an initial set of parameters to be defined for all three species. A sensitivity analysis involving responses in total dry matter (TDM), green dry matter (GDM), leaf matter (LM) and their total sum to a 10 per cent change in each parameter individually was carried out with the model to identify those parameters leading to the greatest variation in model output for further consideration. Selected parameters were then varied by a multiplier within a range of 0.4 and 2.0 with the model run for ten years and an error sum of squares (ESS) calculated between outputs where the parameter had been changed and those with the original set. Further information was then obtained in the form of expert opinion (DJ Moot, Lincoln University, pers com. 2010), and from the literature (in particular, Skinner *et al.* 2008; Peri *et al.,* 2005; Peri *et al.,* 2002; Woodward, 1997, 1998) to assist in refining estimates for the most sensitive parameters. A description of the resulting parameters, their values and the source of the estimates are presented in Table 3.1. Further details of their derivation are given in Gicheha (2011).

Table 3.1: Parameters estimates for cocksfoot, annual ryegrass and lucerne pastures for the canopy growth model

Parameter number	Parameter	Description[1]	Pasture type[1]			Units
			Cocksfoot	Annual ryegrass	lucerne	
	Growth model parameters					
1	GV[gv_Y]	efficiency of converting substrate to structure	0.75 (39)	0.76 (14,39)	0.75 (40)	mg[CO$_2$](kgDMha^{-1})$^{-1}$
2	GV[gv_pieV]	assimilate partition to vegetative growth	0.60 (16)	0.60 (27)	0.88 (8)	mg[CO2]m^{-2}
3	GV[gv_pieR]	assimilate partition to reproductive leaf	0.66 (38)	0.67 (20, 27)	0.88 (8)	″
4	GV[gv_pieS]	assimilate partition to reproductive stem	0.3 (38)	0.26 (27)	0.27 (6)	″
5	GV[gv_pieL]	assimilate partition to root	0.68 (40)	0.68 (40)	0.60 (5)	″
6	GV[gv_gamma]	conversion (kgDMha^{-1} to mgCO$_2$m^{-2}) mass	161 (39)	161 (39)	161 (39)	mg[CO$_2$](kgDMha^{-1})$^{-1}$
7	GV[gv_R]	target mass	1.0	1.0	2.0 (33)	
8	GV[gv_deltaE]	worm removal constant	0.0005 (38)	0.0005 (38)	0.0005 (38)	
9	GV[gv_deltaD]	base decomposition rate	0.0148 (1)	0.0148 (1)	0.0148 (1)	kg ha^{-1} d^{-1}
10	GV[gv_sigma]	leaf senescence rate	0.0011 (39)	0.0012 (18)	0.0011 (39)	kg ha^{-1} d^{-1}
11	GV[gv_R$_{m1}$]	dark respiration	1.72 (1)	1.6 (22)	4.32 (33)	mg[CO2]g-^{1}h^{-1}
12	GV[gv_R$_{m2}$]	leaf respiration	0.08 (1)	0.061 (14)	0.078 (1)	mg[CO$_2$]g-^{1}h^{-1}
13	GV[gv_stress1]	water stress lower limit	-2.2 (10)	-2.5 (7)	-3.8 (37)	Mpa
14	GV[gv_stress2]	water stress upper limit	-0.2	-0.5	-0.2	Mpa
	Photosynthesis model parameters					
15	Q	maximum photosynthesis at reference temperature	1.17 (29, 38)	0.82 (14)	2.0 (38)	mg[CO$_2$]m^{-2}(leaf)s^{-1}
16	T$_{ref}$	optimal temperature	21 (13, 32)	20 (23, 26, 36)	20.0 (2)	^{o}C
17	T$_0$	half optimal temperature	1.0 (38)	1.0 (38)	40.0 (8)	^{o}C

Table 3.1: — Contd'

Parameter number	Parameter	Description[1]	Pasture type[1]			Units
			Cocksfoot	Annual ryegrass	lucerne	
18	Alpha	peak leaf photosynthesis efficiency	0.01 (15)	0.076 (19)	0.022 (32)	$mg[CO_2]J^{-1-}$
19	Theta	curvature parameter in leaf photosynthesis response	0.81 (38)	0.86 (15)	0.61 (32)	Dimensionless
	Reproduction model parameters					
20	A	minimum sustainable SLA	0.0075 (1)	0.04 (30)	0.092 (11)	m^{-2}(leaf) m^2
21	B	difference between A and SLA when grown in the dark	-0.001 (1)	-0.078 (1)	-.0017 (11)	″
22	C	instantaneous rate of change of SLA	0.1661 (1)	0.165 (20)	0.0 (11)	″
23	M	rate of stem maturation	0.09 (38)	0.09 (38)	0.0 (32)	$Mg[CO_2]m^{-2}\ d^{-1}$
24	Flg	flag leaf fraction of the total reproductive leaf	0.21 (1)	0.21 (1)	0.0 (32)	
25	t1	day when stem elongation start	273 (24)	282 (16)	320 (14)	days
26	t2	day when stem maturation starts – day of ear emergence	306 (24)	296 (16)	90 (14)	days
27	t3	day when stem senescence starts	324 (24)	315 (16)	90 (14)	days
28	t4	day when stem elongation ceases	333 (24)	324 (16)	75 (14)	days
	Light capture model parameters					
29	K	extinction coefficient	0.44 (12)	0.63 (21, 27)	1.03 (34)	m^{-2} (ground) m^2 (leaf)
30	Kv	extinction coefficient vegetative leaf	0.88 (37)	0.88 (37)	0.94 (10)	″
31	Kr	extinction coefficient reproductive leaf	0.92 (37)	0.92 (37)	0.94 (10)	″
32	Km	extinction coefficient reproductive stem	0.92 (37)	0.92 (37)	0.94 (10)	″
33	Epsilon	reproductive leaf elevation	0.0008 (37)	0.0011 (37)	0.0008 (37)	kgDM ha^{-1}

Table 3.1: — Contd'

Parameter number	Parameter	Description[1]	Pasture type[1]			Units
			Cocksfoot	Annual ryegrass	lucerne	
34	c_m	light capture efficiency of mature stem	0.003 (15)	0.003 (15)	0.003 (15)	ha kgDM^{-1}
35	c_d	light capture efficiency of leaf, sheath and dead material	0.009 (15)	0.009 (15)	0.009 (15)	″
36	c_{mr}	light capture efficiency of reproductive stem and leaf	0.00046 (15)	0.00046 (15)	0.00036 (15)	″
37	w_d	proportion of dead material in mixed layer	0.28 (33)	0.28 (33)$^{)}$	0.28 (33, 39)	kgDM ha^{-1}
	Specific leaf area model parameters					
38	minSLA	leaf area ratio of vegetative green	0.0019 (37)	0.00186 (211)	0.0019 (33)	ha (leaf) kgDM^{-1}
39	invCoff	inverse coefficient (SLAc)	0.133 (23)	0.165 (33)	0.60 (33)	
40	sigA	leaf lifespan (SigA)	0.00057 (38)	0.00038 (17)	0.0003 (33)	days
41	sigB	leaf lifespan (SigB)	0.0074 (17)	0.0072 (17)	0.007 (33)	days
42	Cubic	current day of the year	10 (24)	102 (17)	180 (32)	days
43	Quad	reference day	80 (17)	249 (17)	30 (32)	″
44	Linear	Percent	0.80 (24)	0.66 (24)	1.0 (32)	percent
45	Const	Percent	0.50 (24)	0.88 (24)	1.0 (32)	″

[1] Reference number corresponds to the number given in brackets

1 Atkin *et al.* (2000)
2 Bates (2009)
3 Bowley *et al.* (1988)
4 Brown (2004)
5 Cunningham & Volenec (1998)
6 Durand *et al.* (1997)
7 Duru & Langlet (1995)
8 Fick *et al.* (1988)
9 Garrier and Roy (1988)
10 Gosse *et al.* (1982)
11 Gosse *et al.* (1984)
12 Hamid-Auda *et al.* (1966)
13 Hansen & Jensen (1977)
14 Hare (1986)
15 Johnson *et al.* (1995)
16 Kathryn *et al.* (2004)
17 Lemaire & Agnusdei (2000)
18 Li *et al.* (1996)
19 Liang *et al.* (2002)
20 Lötscher *et al.* (2003)
21 Ludlow (1985)
22 Musil *et al.* (2009)
23 Peacock (1975)
24 Peri (2002)
25 Rapacz *et al.*(2007)
26 Ryle (1970)
27 Sheehy & Chapas (1976)
28 Sheehy & Peacock (1975)
29 Smith (1950)
30 Tanaka (1976)
31 Taylor *et al.* (1968)
32 Teixeira (2006)
33 Thornley & Johnson (2000)
34 van Henten & van Straten (1994)
35 Wiesner & Grabe (1972)
36 Whitfield *et al.* (1986
37 Woodward (1997)
38 Woodward (1998)

The process of estimating parameter values for simulating lucerne growth followed that for annual ryegrass and cocksfoot. Sensitivity analysis of the model parameters showed a similar pattern to the grasses. Where values were not available for lucerne specifically, those from pasture species with similar growth characteristics were obtained. In addition to the parameters presented in Table 3.1, the lucerne model utilises the root component which requires an extra 9 parameters shown in Table 3.2. 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 the taproot and crown, mainly in the form of starch (McAdam & Nelson, 2003).

Table 3.2: Lucerne root growth model parameters

Parameter number	Parameter	Description	Value	Units	Source
46	qt	Q tops	0.47	mg[CO$_2$]m^{-2}(leaf)s^{-1}	Smith (1950)
47	rt_resp	root respiration	0.015	mg[CO$_2$]g-^{1}h^{-1}	"
48	st_alpha	recycled DM	0.1315	kg DM ha^{-1}	Li *et al.* (1996)
49	st_gamma	recycled DM	895	"	Bowley *et al.* (1988)
50	rc_alpha	recycled DM	1.7	"	Bowley *et al.* (1988)
51	rc_gamma	recycled DM	0.0	"	*Estimated*
52	rc_d1	recycled DM–day lower limit	35	day	Teixeira (2006)
53	rc_d2	recycled DM–day upper limit	212	"	"
54	rm_pie	used in apportioning while vegetative	2.0		"

A sensitivity analysis was also carried out for the root model parameters and, with the exception of the parameter describing recycled dry matter (*rc_alpha*), they were shown not to significantly affect the TDM, GDM and LM components.

LincFarm has not previously included a germination routine so in order to simulate growth of annual pasture species, a germination procedure has been developed. Temperature (expressed as thermal time requirements for germination and emergence) and rainfall are required for seeds to germinate and emerge. The model simply accumulates thermal time (Tt), also known as heat units or growing degree days, and rainfall after the sowing date and once the threshold values are reached, the crop is assumed to be established. Estimated germination and emergence thermal time (Tt) requirements for annual ryegrass are 90 and 145 degree-days (^{o}Cd) respectively (Moot *et al.*, 2000). Rainfall of 10.0-13.0 mm after 1st of March (Cocks & Donald, 1973; Gramshaw & Stern, 1977) has been shown 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, a number of leaves per tiller of 3.2 and a total number of tillers of 25 at day 35 after sowing. This information, together with a seed sowing rate of 18.0-25.0 kg ha^{-1} (Agricom, 2010), estimates of 100,000 seeds of annual ryegrass per kilogram seed, and a 90.0 per cent germination rate (Hill *et al.,* 1985), was used to estimate an initial mass of annual ryegrass at germination of 22.14 kg DM ha^{-1}.With inclusion of the germination procedure in LincFarm and specification of parameter values described in Table 3.1, the model was evaluated against data for cocksfoot and annual ryegrass (six data-sets for each pasture type) provided by the New Zealand Plant Breeders Research Association (L.Dick, NZPBRA, pers. com., 1999) and unpublished data on lucerne growth at Lincoln, New Zealand from Smetham (1970). Plots of model estimates against the data are shown in Figures 3.1 – 3.3 and statistics of fit using methods described by Kobayashi & Us Salam (2000) are given in Table 3.3.

Estimated growth rates of cocksfoot against NZPBRA field data are shown in Figure 3.1. Modelled pasture growth rates for cocksfoot were generally within one standard deviation of the mean field data except for a period around April and December when it fell below the data and in a period after August when it slightly overestimate growth rate.

Figure 3.1: Plots of model output (◆) for cocksfoot growth rate compared to observed growth data (○) from NZPBRA field experiments

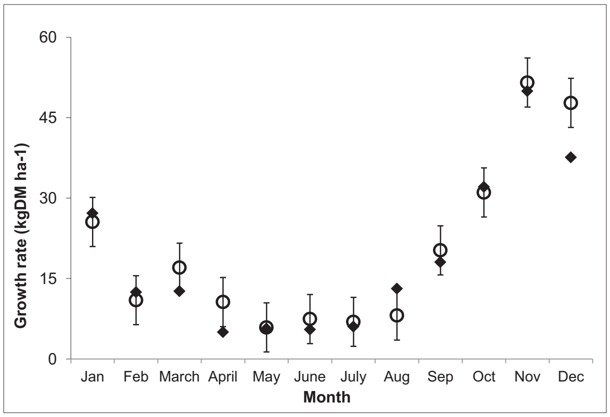


Figure 3.2 shows model estimates of annual ryegrass yield against measured growth data over two years from NZPBRA. Model values match the field data except for some data points around October 1995 and May 1996 which fell outside one standard deviation of the mean values. The pattern of change in growth rate with season closely mirrored that observed in the trials. Annual ryegrass is assumed to die approximately 14 days after flowering which explains its sharp decline after November following flowering.

Figure 3.2: A comparison between simulated (♦) annual ryegrass yield and data (○) from NZPBRA field experiment

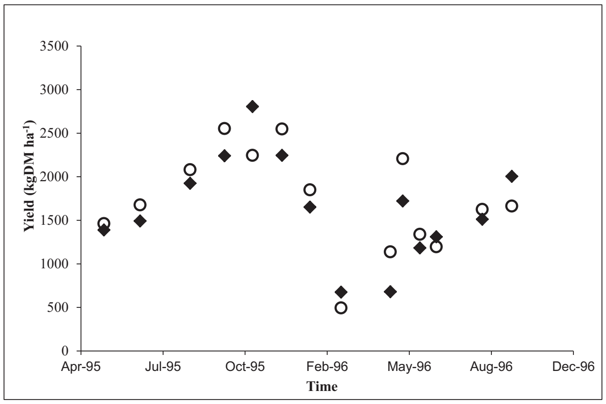
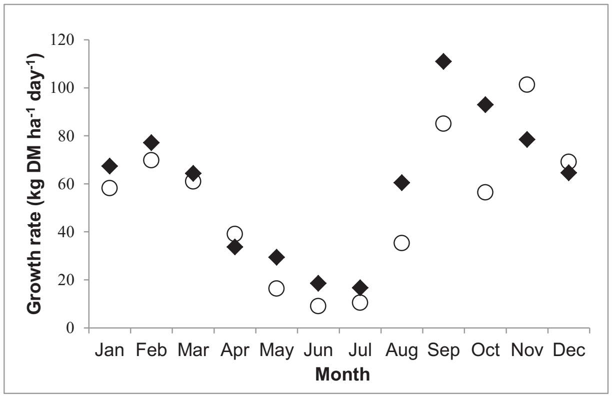


Figure 3.3 shows plots of model output and unpublished data on growth rates of pure lucerne grown at Lincoln from Smetham (1970). Generally, the modelled growth rates were within one standard deviation of the field data with the exception of a period around May and another around August - October when the model tended to overestimate the growth rate.

Figure 3.3: Plots of model output (♦) for lucerne growth rate compared to unpublished growth data (○) from Smetham (1970)



In all other instances, the model prediction fell within one standard deviation, suggesting that the model parameters obtained from the literature search are sufficient to simulate lucerne growth and productivity in this environment.

Table 3.3 presents a summary of statistics for the pasture model evaluation. Statistical methods from Kobayashi & Us Salam (2000) include the mean squared deviation (MSD) and root mean squared deviation (RMSD) which indicate the overall deviation of the model output from the measured value. MSD is then partitioned into components which represent different aspects of the deviation. The squared deviation or SB measures the difference between the means of the predicted and observed values. The difference between the standard deviations of the predicted and observed values (SDSD) indicates the extent to which the model fails to simulate the magnitude of fluctuation among the *n* observations, and the lack of positive correlation weighted by the standard deviations (LCS) shows the extent to which the model fails to simulate the pattern of fluctuations across the *n* measurements.

Table 3.3: Statistics for the set of pasture model parameters[1] used in simulating yield (kg ha^{-1}) of cocksfoot, annual ryegrass and lucerne

Criterion[2]	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

[1] See Tables 3.1 and 3.2 for the parameters
[2] See text for description of the evaluation criteria

In general the RMSD in kg ha^{-1} is quite low which is reflected in the high values of the correlation coefficients for all three species indicating that only small differences exist between model output and measured values. In all cases, LCS which relates to the pattern of fluctuations across the measurements, is the major component contributing to MSD. For instance for cocksfoot, it contributed 79.37 per cent of the MSD while SB, which measures the difference between the means of the predicted and observed values, only contributed 12.90 per cent. SDSD, which reflects the ability to simulate the magnitude of fluctuations among the observations, is very small in all cases.

3.2 Development of a simple crop model for brassicas

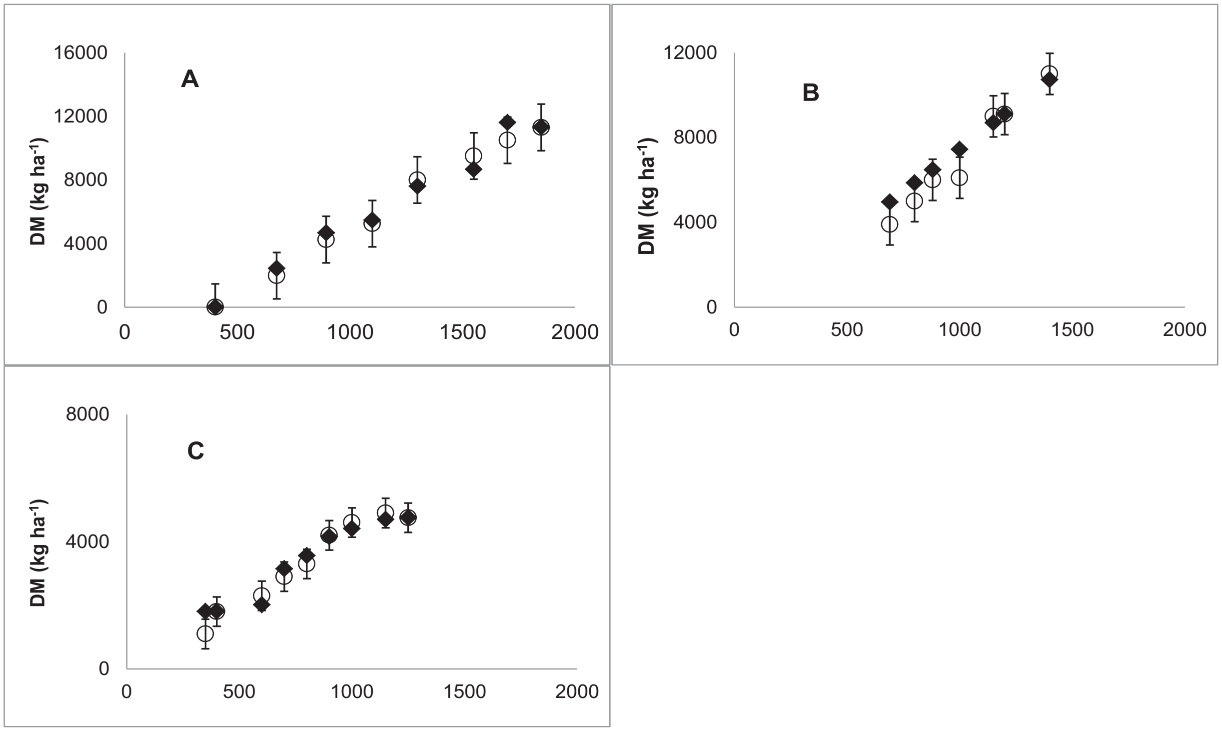
Thermal time (Tt) has been proposed to describe the phenological development of plants as an alternative to calendar days in projecting crop yield (Morrison *et al.,* 1989). Various studies have established a linear relationship between number of leaves per stem and accumulated temperature (^{o}Cd) in wheat (Gallagher, 1979), corn (*Zea mays* L.) (Warrington & Kanemasu, 1983), summer rape (Morrison & McVetty, 1991), Pasja or leaf turnip (*Brassica campestris x napus*) (Nanda *et al*., 1995), and kale (Wilson *et al*., 2004). Adams *et al.* (2005) observed that yield of brassicas (Goliath rape, Green Globe turnip, Gruner kale and Kestrel kale) was linear in relation to Tt. Chakwizira (2008) identified a strong linear relationship (R^2=0.99) between dry matter accumulation and Tt for kale and Pasja, with and without phosphate fertiliser application, of 800.0 and 420 kg DM ha^{-1} for every 100.0 ^{o}Cd respectively (mean of all P fertiliser treatments) with a base temperature of 0.0 ^{o}C (Moot *et al*. 2007). Adams *et al.* (2005) obtained a value of 667 kg DM ha^{-1} for every 100.0 ^{o}Cd for rape with a base temperature of 4.0 ^{o}C. Though other production factors such as soil fertility, pest and diseases affect forage crop dry matter accumulation, most often the main yield limiting factor is soil water (Wilson *et al.,* 2006). Hence soil moisture has been included as a modifier in an equation for estimating the dry matter accumulation of Brassicas:

$$DM = DMAccumulationPer^{0}Cd \times Tt \times MoistureModifyer$$

Where $DMAccumaltionPer^{0}Cd$ represents the amount of dry matter accumulated per ^{o}Cd and *MoistureModifier* is the ratio between actual evapo-transpiration and potential evapo-transpiration. Comparison of dry matter accumulation of kale, rape and leaf turnip from this simple model with data from Chakwizira (2008) and Adams *et al.* (2005) shows that, the modelled dry matter for these forage crops fell within one standard deviation of experimental values (Figure 3.4).

Pasja differs from kale and rape in that it has a crown, usually at or below ground level, from which leaves grow, enabling leaf regeneration after defoliation. Input variables for the model allow the user to define the minimum pasture cover (in per cent) 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. Chakwizira (2008) established that the high leaf to stem ratio obtained for Pasja indicated that its dry matter was essentially made up of leaf with the crown constituting less than 6.0 per cent of dry matter (48.0 g m^{-2}). This is similar to the value of approximately 8.0 per cent reported by Wilson *et al*. (2006). Thus, since growth 1 occurs from the crown, dry matter accumulation for Pasja does not start at zero.

Figure 3.4: Observed (○) and model predicted (♦)values for (A) kale, (B) forage rape, and (C) pasja DM accumulation



3.3 Beef growth and composition model

The third extension to LincFarm required for the analysis is inclusion of a beef cattle growth model. Oltjen *et al.* (1986) described a dynamic model of post-weaning growth and composition in beef cattle (Davis Growth Model; DGM) based on fundamental biological concepts of hyperplasia and hypertrophy, earlier developed by Baldwin & Black (1979) and Burleigh (1980), but applied at the whole animal level. The DGM was chosen to simulate growth and composition of young cattle under New Zealand grazing conditions because it explicitly represents factors such as the animal's genetic background and nutritional history which are important determinants of performance when extended to new situations (Oltjen *et al*., 1985; Sainz *et al*., 1995).

The DGM was originally parameterised using individual data from Garrett (1980) and Byers & 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 for the model when applying it to different production systems.

In the New Zealand study of Kitessa (1997), 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 Hereford x Angus yearling heifers were used with an additional 9 heifers in experiment II grazed alone on continuous or rotational pastures. Parameters of the DGM were estimated and evaluated by simulating results for LW and intakes from Kitessa (1997) experiment I and experiment II, respectively. Measurements were made of the initial and final LW, and the average daily intake (DMI). Data on the weights of muscle (m), viscera (v) and fat (f) were not measured. Subsequently, the model was tested against data from Sainz *et al*. (1995) to ensure net energy for gain (NE_g) is apportioned amongst m, v and f correctly. Initial parameter values were taken from Oltjen *et al.* (2006) while the optimised values obtained using data from Kitessa (1997) experiment I are shown in Table 3.4.

Table 3.4: Estimates of the growth and composition parameters for cattle based on the data of Kitessa (1997) experiment I

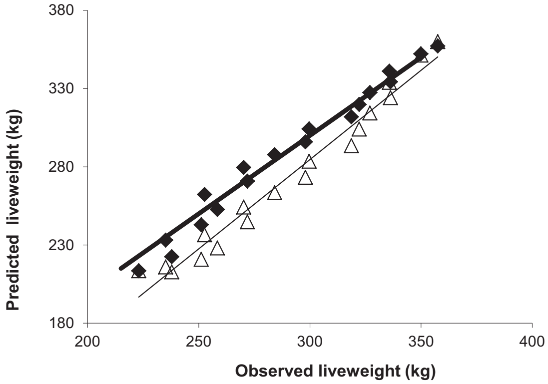
Parameter[1]	Fitted Value	Standard deviation	% change[2]	Units
p_m	0.3973	0.035	12.48	-
P_v	0.053	0.001	6.00	-
c_m	1463.649	32.420	9.23	kJ d^{-1}
CS_1	0.293	0.008	-6.69	Day
CS_2	0.045	0.001	8.17	day kJ^{-1}
b_1	0.986	0.143	-3.62	MJ $d^{-1}kg^{-1}$
b_2	9.327	0.332	-11.51	MJ $d^{-1}kg^{-1}$
e_2	3.104	0.085	-8.71	-

[1] See Oltjen *et al.* (2006) for a description of the parameters

[2] Change from original parameter values of Oltjen *et al.* (2006)

Plots of observed and predicted values using parameters obtained from Oltjen *et al.* (2006) and the set obtained in this study are shown in Figure 3.5 for the LW data from Kitessa (1997) experiment II.

Figure 3.5: Observed and predicted values for average LW for animals with data from Kitessa (1997) experiment II, utilising parameters from Oltjen *et al.* (2006) (-△-) and parameters estimated in this study (◆); ── y=x



Results indicate that the simulation using parameter values established here falls almost exactly on the line where predicted equals observed (y=x).

Since these data were for overall growth and not composition, the estimated parameters were further tested against data from Sainz *et al.* (1995) in partitioning NE_g into m, v and f. The data-set contains measurements of feed energy concentration, DMI, and initial and final body composition of 120 Angus-Hereford steers, fed a high or low concentrate diet in two phases. During the growing phase, the low-concentrate diet (ME = 7.8 MJ kg^{-1}) was fed *ad libitum* (FA) and the high-concentrate diet (ME =12.8 MJ kg^{-1}) was fed *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 *ad libitum* (CA) or restricted to 70.0 per cent *ad libitum* intake (CL). This resulted in five groups of animals with different growth paths: CA-CA, CL-CA, CL-CL, FA-CA and FA-CL. An additional group was slaughtered at the beginning to estimate the initial body composition of the steers.

Table 3.5: 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

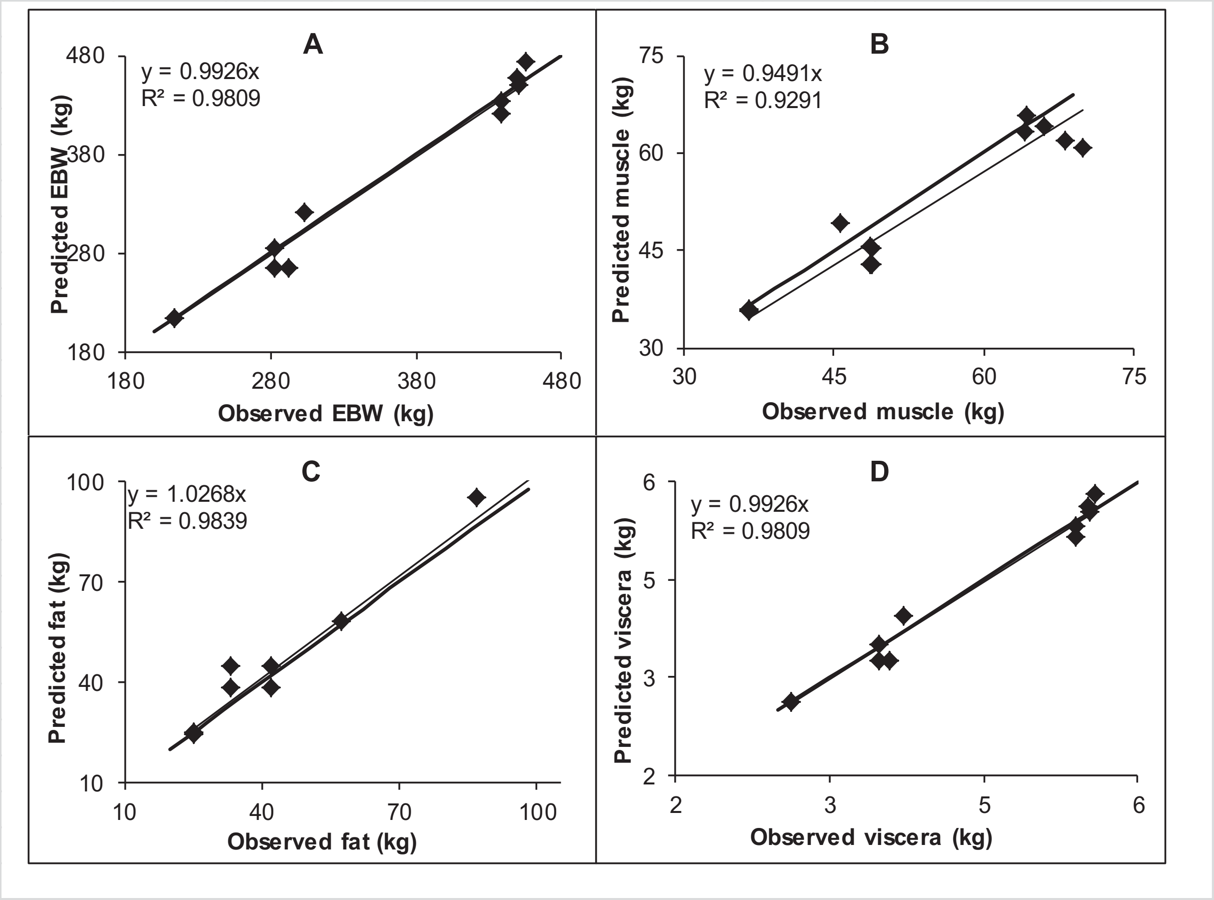
		Treatment[1]				
Component		CA-CA	CL-CA	CL-CL	FA-CA	FA-CL
EBW (kg)	Obs.	451.00	449.00	439.00	455.00	439.00
	Pred.	450.89	457.77	433.46	473.96	420.72
	% dif.	-0.02	2.03	-1.26	4.16	-4.16
Protein[2] (kg)	Obs.	69.70	71.60	73.60	69.80	75.40
	Pred.	68.88	69.76	67.21	71.56	65.83
	% dif	-1.17	-2.57	-8.69	2.52	-12.69
Fat (kg)	Obs.	116.70	106.90	96.50	116.40	86.60
	Pred.	109.99	112.05	101.05	119.43	95.32
	% dif.	-5.75	4.81	4.72	2.61	10.06
Viscera (kg)	Obs.	5.54	5.51	5.39	5.59	5.39
	Pred.	5.53	5.62	5.32	5.82	5.17
	% dif.	-0.02	1.95	-1.30	4.18	-4.14

[1] See text for the treatments description

[2] Protein equals the sum of *m* and *v*

Values for initial EBW and its components were set at 214.0 kg for EBW, 36.74 kg *m* and 25.2 kg *f* corresponding to values reported in Sainz *et al.* (1995). The value of *m* was obtained by subtracting *v* from total protein. Initial *v* weight was assumed to be 16.58 per cent of the sum of the liver, heart, kidney, spleen and gastrointestinal tract weight (Oltjen *et al.,* 2000), equivalent to 6.0 per cent of LW (Soboleva *et al.,* 1999). Table 3.5 and Figure 3.6 shows comparisons 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 are less than 5 per cent in most cases and show that the model reproduces well the experimental results with a good prediction of EBW mass (Figure 3.6A; bias = -0.008), and of *m* (Figure 3.6B; bias = -0.0509), *f* (Figure 3.6C; bias = + 0.0268) and *v* (Figure 3.6D; bias = -0.008) components of the EBW.

Figure 3.6: Observed (Sainz *et al.,* 1995) and predicted values for EBW mass (A), muscle (B), fat (C) and viscera (D); —— regression of y on x ; —— y=x



The beef growth and composition model as described was incorporated into LincFarm and the extended model tested to verify that the outputs of LW, EBW, protein, fat and MEI were the same as for the stand-alone model, and that other 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) also operated correctly.

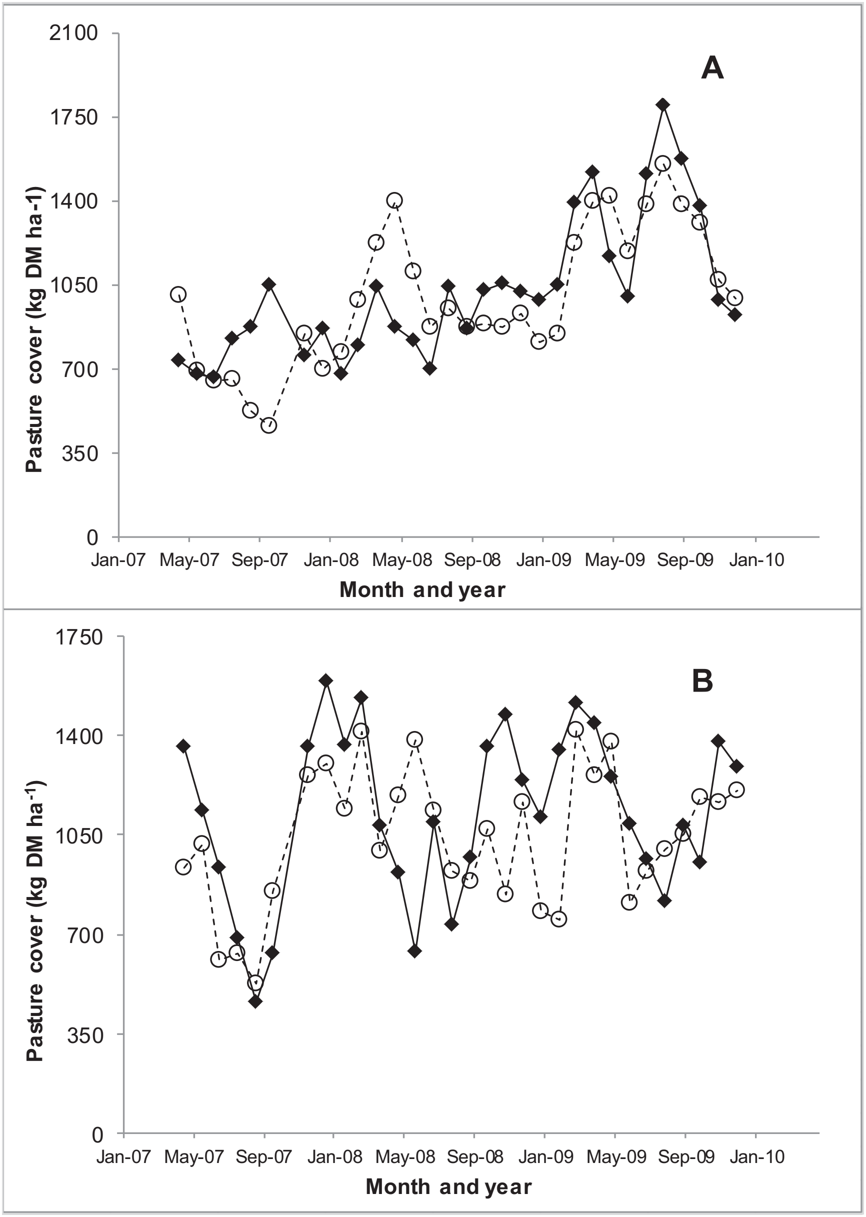
3.4 Evaluation of the Revised LincFarm Model

Two simulations representing the legume and grass units in the field trials summarised in section 2 were performed in evaluating the revised LincFarm model. Model variables were set to correspond to the pasture, animal, management, and experimental treatments being tested in the trial as described in Bywater *et al.* (2010). The following discussion is confined largely to the new elements of LincFarm described above. Existing aspects of the model have been evaluated previously (Bywater *et al.*, 2000; Cacho *et al.*, 1995; Finlayson *et al.*, 1995).

Model evaluation methods described in Kobayashi & Us Salam (2000) were used in the comparison. Figure 3.7 shows predicted pasture covers for the grass and legume based units against those observed in the trial and Table 3.6 presents summary validation statistics between the two. RMSD which represents the mean distance between the model and the data was 48.03 and

102.66 kg DM ha^{-1} for the grass and legume based systems, where average covers over the whole period were 907.2 and 1121.9 kg DM ha^{-1} respectively.

Figure 3.7: Comparison of simulated pasture covers (—♦) for the grass- (A) and legume-based (B) systems compared with data from the trial units (- -○- -) for the production period 2007/08 to 2009/10



Pasture cover is the summation of a number of variables in the system and as such is generally difficult to predict accurately. The relatively high values of the correlation coefficients between simulated and measured pasture cover (*r)*, especially for the grass system, shows the model is capable of simulating pasture cover reasonably well. The standard deviations of the measurements (SD_m) are higher than those for the simulation (SD_s) which is consistent with the bigger difference in the SDSD or magnitude of fluctuations between the simulation and measurement (Kobayashi & Us Salam, 2000) than in the pattern of fluctuations (LCS) for both units but particularly the legume unit.

The high MSD value for the legume farm system indicate the overall deviation is not entirely dependent on the correlation ($r = 0.63$) but mainly due to the expected high variability between measurement and simulation. Lucerne pastures in the trial were old and were thought to perform poorly (Bywater *et al.*, 2010) resulting in slightly bigger difference than might otherwise have been the case between the simulated and observed cover in the legume system.

Table 3.6: Summary validation statistics for the model against pasture cover data for grass- and legume-based trial farm units obtained from Bywater *et al.* (2010)

Criterion	System	
	Grass-based	Legume-based
MSD	2333.20	10539.74
RMSD	48.03	102.66
SB	494.76	873.28
SD_s	163.88	178.16
SD_m	198.23	257.76
LCS	658.52	3330.30
SDSD	1179.92	6336.16
R	0.89	0.63

A major contributing variable to pasture cover is pasture growth rate and Table 3.7 presents summary validation statistics for switch pasture and lucerne growth rates from LincFarm against data from the trial. Mean simulated growth rates were 4.26 and 4.65 kg DM ha^{-1} day^{-1} greater than the data for switch and lucerne respectively. The SDSD and LCS which indicate differences in the magnitude and patterns of fluctuations (Kobayashi & Us Salam, 2000) are small for both pastures. This results in a small MSD implying that there is little difference between measured and modelled growth rates, which is supported by the high r values.

Table 3.7: Summary validation statistics for the model against switch and lucerne pasture growth rate data obtained from the legume-based trial unit (Bywater *et al.*, 2010)

Criterion	Pasture type	
	switch	Lucerne
MSD	18.13	21.64
RMSD	4.26	4.65
SB	10.15	15.63
SDSD	5.51	3.94
LCS	2.47	2.07
R	0.78	0.71

Data were available for kale yields for 2008/09 and 2009/10 (Bywater *et al.*, 2010). In the first season, yield data were based on the kale variety planted while in the second they were reported for specific paddocks. Figure 3.8 presents a comparison of the modelled kale yields and the data. The model overestimated kale yield in both seasons. However, the difference was highest for kale variety 1 in 2008/09. The low yield was attributed to the kale cultivar planted, coupled with late sowing. Following that observation, corrective measures were applied in the trial resulting in the higher yields obtained the following season. Model estimates are still slightly higher than the data for 2009/10 but are more comparable and in fact were closer to expectations that the actual yields (Bywater *et al.*, 2010).

Figure 3.8: Comparison of simulated kale yield with observed data from the trial for 2008/09 (A) and 2009/10 (B)

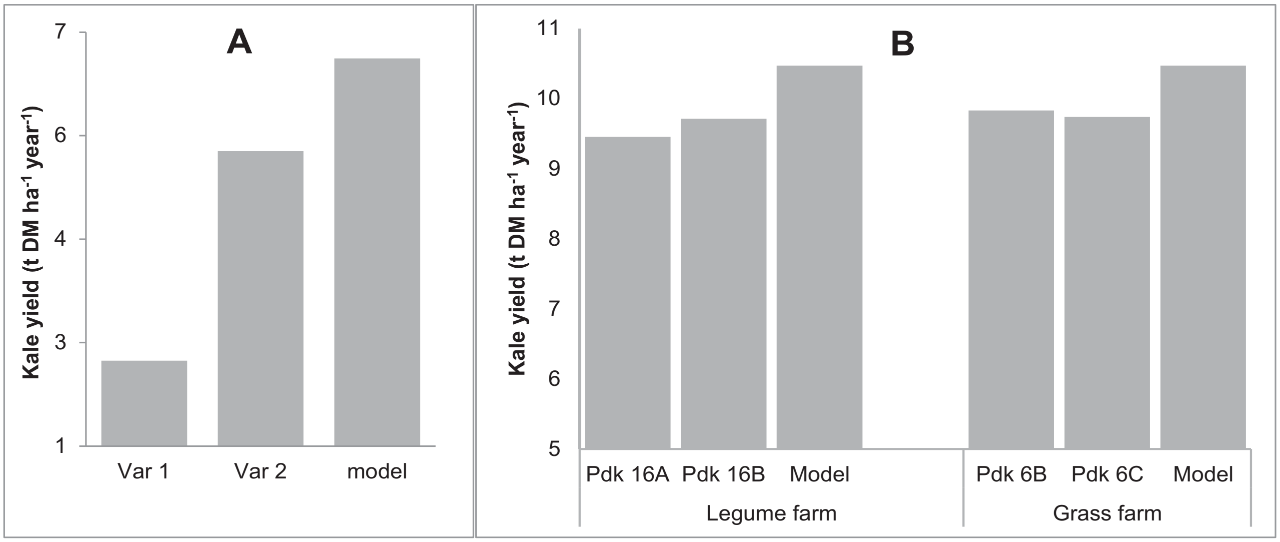


Table 3.8 shows a comparison of average cattle sale weight from the trial with that from LincFarm over three seasons. The difference ranges between +3.0 per cent and -3.0 per cent with the model tending to slightly under-estimate cattle LW in the first season which was the establishment year of the trial and a poor season, and the last, which was a good production year.

Table 3.8: 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

Overall the extended model results represented the field trials sufficiently well to be judged adequate for the purposes of the analysis to be conducted.

Chapter 4
Simulation Analysis of Alternative Strategies on Dryland Sheep Farms

In the trials at Silverwood summarised in section 2, two different feed supply systems were evaluated each at a single stocking rate and with a fixed stock policy. Funding was sufficient for full data collection for two years only and although climate conditions were quite different in each year, two years represents a very small sample of the possible weather patterns which can be experienced on the Canterbury Plains and the rest of the east coast.

As noted in section 3, the plant growth model in LincFarm is driven by daily climate data and the system can be run for as long as suitable weather data are available. It is also possible to identify different combinations of pastures, crops and livestock so that a range of farm policies can be analysed with different management. The farm trials have therefore been extended by analysing a range of farm strategies on a hypothetical farm, based on the Silverwood trials, with each run at different stocking rates and with a number of years of climate data.

4.1 Experimental protocol

The hypothetical farm consists of a 100-ha property on the Canterbury Plains divided into 16 equal-size paddocks each measuring 6.25 hectares. Thirteen paddocks are sown in a perennial ryegrass:clover mixed pasture, two paddocks in kale for winter forage, and one paddock in 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. This represents the feed supply system of the grass unit at Silverwood.

The baseline farm is stocked with Coopworth sheep representative of the Ashley Dene breeding flock. Replacement ewes are purchased off-farm with the number depending on the strategy being tested. 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 four stocking rates (SR) of 10, 12, 14 and 16 SU ha^{-1}. Mature ewes are counted as 1.1 SU, rams as 1.0 SU and 18-month-old cattle as 5 SU. The stocking rate is accounted on 1 July, when all lambs are off the farm. The actual stocking rate will be greater during other times of the year and will depend on the number of ewes and the lambing percentage achieved each year.

Lambs are drenched at weaning and subsequently on a monthly basis; in the trial lambs were drenched on faecal egg count (FEC) status after weaning but the model does not have the facility to accommodate this. Lambs are weaned at an average LW of 25 kg and 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 that point all lambs are sold as stores. During the production period, animals are split into mobs with different grazing rules depending on pasture availability, time of year and the relative priorities of different stock. Ewes are set-stocked from one week before lambing to weaning and then both lamb and ewe mobs are rotationally grazed on different pasture types. Barley silage and any feed that is not utilised in the year is conserved and offered to the stock during the following winter, or during other times of feed constraints. Details on the operation of the management calendar, including grazing rules and their implementation, are presented in Finlayson *et al.* (1995).

Weather data used in running the simulations were obtained from the NIWA Virtual Climate Station Network (VCSN). The VCSN data are based on spatial interpolation of data from weather station sites onto a grid of approximately 5 x 5 km resolution covering the whole of New Zealand (Tait *et al.,* 2006). A comparison of weather data obtained from the VCSN for latitude -43.559962, longitude 171.84911 (the location of Silverwood farm) and some limited and sporadic data available from a weather station at Silverwood show that the two are almost identical which confirmed that the VCSN data are suitable for simulating pasture growth at the site.

Each strategy/stocking rate combination was run for 19 years from 1990/91 to 2009/10 with the first 4 years discarded to overcome any issues with 'starting conditions'. Results of all combinations therefore include 15 years of operation up to 2009/2010, the last year of the trial. Actual cost and price data for the same period were obtained from the Financial Budget Manual published by Lincoln University annually up to 2000 and biennially thereafter (LU, 1991- 2010). These manuals give comprehensive data on prices and costs of various agricultural materials and activities regionally throughout New Zealand, including weekly stock prices. Prices for the period from October to February inclusive were used as these cover the sale period relevant to the analysis.

The seven strategy options with different combinations of pasture types and stock classes were chosen because they were considered to include flexibilities which have the potential to reduce the negative impact of climatic variability on productivity and profitability in high performing dryland sheep systems. These flexibility options were based on experience gained in defining and running the Silverwood grass and legume systems which was done in consultation with a farmer reference group in the study area. The seven strategies are:

1. The baseline hypothetical farm described above stocked with sheep at 10, 12, 14 and 16 SU ha^{-1}.

2. The baseline farm as in strategy 1 above but with 25.0 per cent of the ewes replaced with equivalent cattle stock units, bought in May, sold at weight from October, or when pastures dry out. The cattle are rotated through ewe mobs to retain pasture quality.

3. The baseline farm as in strategy 1 but with introduction of a 1st cycle ewe policy; mating all five years old ewes on March 20 for 20th August lambing; drop 2 paddocks out of last round in autumn to build cover for spring.

4. A combination of strategies 2 and 3; i.e. including cattle and a 1st 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; 1st cycle ewe policy at 12.5 per cent of ewes mated to lamb 13th 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; 1st cycle ewe policy at 18.5 per cent of ewes, no cattle.

Strategies 2 and 7 run at 14 SU ha^{-1} represent the grass and legume farm units respectively at Silverwood. With each of the 7 strategies evaluated at four stocking rates, this results in 28 flexible management combinations.

Marketing targets for all of the 28 strategies were set with weaning and drafting weights for lambs noted above and with cattle sold at the end of December. In the event that moisture levels in the top 25 cm of soil (SML_{25}) dropped below 10 per cent, intervention de-stocking was triggered with stock sold according to a priority ranking. The SML_{25} trigger level of 10 per cent and the priority ranking listed below were those used in the Silverwood trials and were implemented in LincFarm through the de-stocking and marketing algorithm described by Gicheha *et al.* (2013 a). Priority rankings were:

a. sell cattle;

b. wean 1st cycle mob, draft lambs, sell cull ewes;

c. wean main mob, draft lambs, sell any cull ewes;

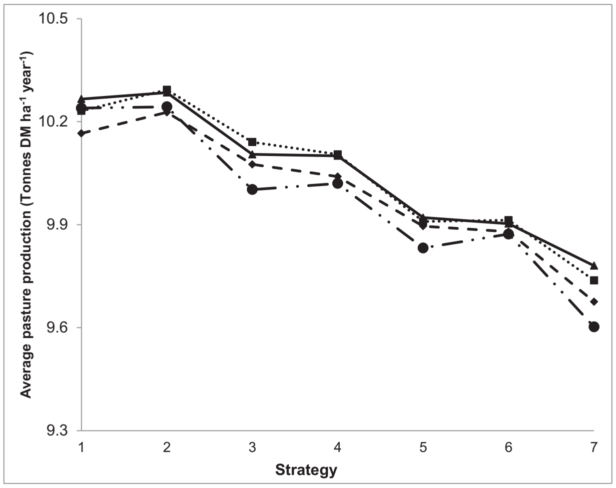
d. review lamb retention by checking feed available for ewes (calculate requirement to end of February based on zero growth rate, including designated lamb feed and determine any land available for lambs) and retain only those lambs that can be finished after allowing for ewe requirements; sell remaining lambs to the store market.

This priority ranking applies to those strategies that include cattle (strategies 2, 4, and 6); for those which do not include cattle, option b) becomes the 1st rank destocking option.

4.2 Results

Figure 4.1 shows pasture production (t DM ha^{-1} year^{-1}) for strategies 1-7 at stocking rates of 10, 12, 14 and 16 SU ha^{-1}. Production ranged between 9.60 t ha^{-1} year $^{-1}$ for strategy 7 at 16 SU ha^{-1} and 10.29 t ha^{-1} year^{-1} for strategy 2 at 10 SU ha^{-1}. Production varied between strategies and SU ha^{-1}. Generally, 14 SU ha^{-1} resulted in higher pasture production compared to 10, 12 and 16 SU ha^{-1} for strategies 1-7. In all strategies, 16 SU ha^{-1} recorded the lowest pasture production with strategy 7 at 16 SU ha^{-1} resulting in the least pasture production overall.

Figure 4.1: Average annual pasture production for strategies 1 to 7 at 10 (■), 12 (♦), 14 (▲), 16 (•) SU ha^{-1}



Strategies 5, 6 and 7 which include increasing areas of switch pastures and lucerne, generally resulted in lower pasture production than strategies 1, 2, 3 and 4, utilising conventional pasture mixes for the Canterbury region of grass-clover. This is consistent with the Silverwood trial results in section 2 where average pasture production on the grass unit was 10.414 t ha^{-1} year^{-1}, with 10.336 t ha^{-1} year^{-1} on the legume unit. In highly stocked systems it would be expected that pasture utilisation would be higher 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 quantity of pasture production; however, the quality came with an increased cost in pasture establishment.

Table 4.1: Average lambing percentage for strategies 1-7 at 10, 12, 14, and 16 SU ha^{-1} (the italicized values in parenthesis are coefficient of variation)

	SR (SU ha^{-1})			
Strategy	10	12	14	16
1	138.31 *(0.17)*	138.00 *(0.39)*	137.34 *(1.19)*	137.60 *(1.61)*
2	138.18 *(0.13)*	138.31 *(1.45)*	138.30 *(0.44)*	138.07 *(0.45)*
3	137.83 *(0.31)*	137.44 *(0.26)*	137.38 *(0.76)*	138.14 *(0.78)*
4	137.50 *(0.38)*	138.20 *(0.34)*	138.18 *(2.46)*	137.44 *(3.17)*
5	137.54 *(0.82)*	138.20 *(0.61)*	137.75 *(3.65)*	137.76 *(1.26)*
6	138.22 *(0.74)*	138.20 *(0.32)*	137.38 *(0.89)*	138.07 *(1.06)*
7	138.07 *(1.13)*	137.78 *(1.29)*	137.96 *(2.62)*	137.51 *(4.38)*

Table 4.1 shows lambing percentage for strategies 1-7 at 10, 12, 14 and 16 SU ha^{-1}. Lambing percentage, which was estimated as the number of lambs weaned divided by the number of ewes mated, ranged between 137.34 per cent for strategy 1 at 14 SU ha^{-1} and 138.31 per cent for strategies 1 at 10 SU ha^{-1} and 2 at 12 SU ha^{-1}. The values presented in Table 4.1 are slightly higher than those obtained in the Silverwood trials which averaged 133.3 per cent on the grass unit (equivalent to strategy 2 at 14 SU ha^{-1}) and 119.65 per cent on the legume unit (strategy 7 at 14 SU ha^{-1}) but noting the problems experienced on this unit in the first year as described in section 2. Lambing percent on this unit in year 2 was 132.5 per cent.

Generally, the range in values across all combinations of strategies and SR, and the coefficients of variation (CV) within each combination are quite low which we have previously observed when stock policies include sale of store lambs early. It also reflects the policy of destocking quickly once conditions dry out which is primarily aimed at protecting ewe condition prior to mating. The CV for lambing percentage tends to increase slightly with increases in SR.

Table 4.2: Meat and wool production for strategies 1-7 at 10, 12, 14 and 16 SU ha^{-1} (italicized values in parenthesis are coefficient of variation)

	Meat production (kg ha^{-1})				Wool production (kg ha^{-1})			
	SR (SU ha^{-1})				SR (SU ha^{-1})			
Strategy	10	12	14	16	10	12	14	16
1	250.59 *(1.92)*	302.31 *(2.24)*	364.79 *(0.99)*	431.98 *(1.29)*	78.44 *(0.55)*	83.97 *(0.58)*	116.11 *(0.72)*	117.69 *(1.19)*
2	326.41 *(1.03)*	397.15 *(3.30)*	440.46 *(1.37)*	484.02 *(1.41)*	58.04 *(0.45)*	59.40 *(2.08)*	70.57 *(0.47)*	89.42 *(0.72)*
3	312.91 *(2.75)*	369.16 *(1.13)*	425.3 *(2.46)*	498.42 *(10.18)*	75.83 *(0.36)*	86.44 *(0.68)*	98.24 *(0.88)*	116.51 *(0.99)*
4	372.53 *(1.24)*	433.8 *(1.77)*	476.73 *(1.57)*	534.39 *(1.82)*	63.35 *(0.68)*	75.12 *(0.78)*	62.25 *(2.73)*	69.51 *(2.75)*
5	352.69 *(3.10)*	393.9 *(0.31)*	437.27 *(2.22)*	463.12 *(2.40)*	71.79 *(1.08)*	85.84 *(1.69)*	65.37 *(4.55)*	88.94 *(2.48)*
6	404.06 *(0.93)*	469.98 *(0.10)*	484.92 *(0.02)*	539.09 *(0.96)*	55.58 *(0.85)*	55.01 *(1.05)*	71.31 *(1.39)*	75.78 *(2.30)*
7	311.95 *(2.44)*	346.96 *(1.68)*	342.87 *(7.52)*	344.88 *(7.01)*	57.06 *(1.73)*	68.72 *(2.84)*	69.49 *(4.51)*	78.65 *(4.88)*

Table 4.2 shows net carcass weight and greasy wool production per hectare for strategies 1-7 at 10, 12, 14 and 16 SU ha^{-1}. Meat production ranged between 250.59 and 539.09 kg ha^{-1} for strategy 1 at 10 SU ha^{-1} and strategy 6 at 16 SU ha^{-1} respectively. Total carcass meat production in the trial averaged 243.7 kg ha^{-1} on the grass unit and 164.0 kg ha^{-1} on the legume unit but it should be noted that the drafting weights were lower in the trial. Greasy wool production ranged between 55.01 and 117.69 kg ha^{-1} for strategy 6 at 12 SU ha^{-1} and strategy 1 at 16 SU ha^{-1} respectively. Generally both meat and wool production per ha increased as SR increased from 10 to 16, with the exception of wool production in strategies 4 and 5, and meat production in strategy 7. Strategies incorporating cattle as a flexibility option (2, 4 and 6) obviously had lower wool production on a per hectare basis.

In Strategy 7, increasing SR from 12 to either 14 or 16 resulted in a slight decrease in meat production. The decrease was accompanied by a very large increase in the corresponding coefficients of variation.

Again, coefficients of variation for meat and wool production were generally quite low, increasing slightly with increasing SR.

Table 4.3: A sample gross margin report with results averaged over fifteen years. Range figures represent the minimum and maximum for each row obtained over the fifteen year period

Stocking rate: 16 SU ha^{-1}
Summary of years 5-19

		Range		
	Mean	Max.	Min.	SD
Income ($ ha^{-1})				
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	647.35	888.02	440.14	178.70
Wool	241.58	308.01	163.70	33.69
Total income ($ ha^{-1})	**2, 369.55**			
Expenses ($ ha^{-1})				
Stock				
Replacements	230.28	286.62	174.09	75.16
18-Month cattle	338.64	406.80	245.52	101.75
Interest cost of stock	55.75	73.96	31.29	14.40
Total	**624.67**			
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
Total Direct Costs ($ ha^{-1})	**592.40**			
Gross Margin ($ ha^{-1})	**1,152.48**	1497.49	941.71	219.3
Stock numbers (1 July; head)				
Ewes	1095	1172	977	78
Rams	20	20	20	0
Cattle	72	72	72	0
Lambs	0	0	0	0

Table 4.3 shows a sample gross margin (GM) for strategy 4 at 16 SU ha^{-1} calculated from a series of fifteen consecutive years. Table 4.4 presents average annual GMs for strategies 1-7 at the four stocking rates with their CVs. Income comes from sale of lambs, cull ewes, wool and cattle.

Income variation was highest in strategies including cattle, followed by lambs sold to the works. In all cases, purchase of cattle caused the greatest variation in expenses.

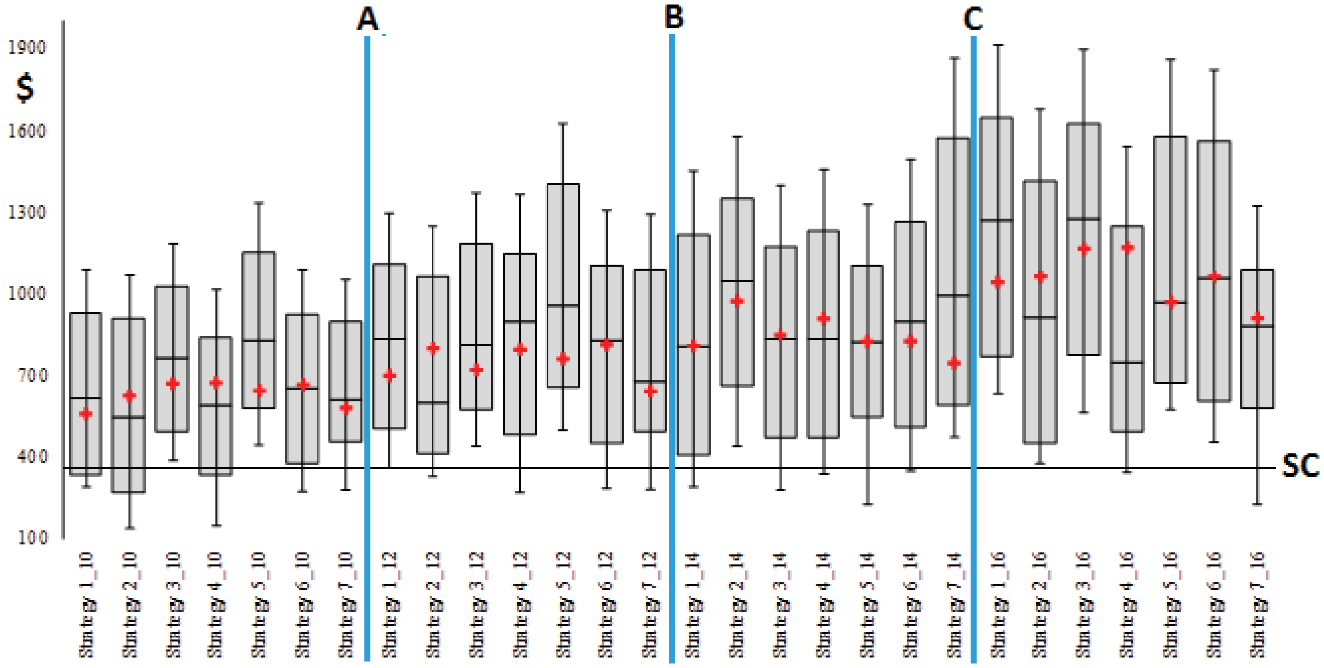
Table 4.4: Gross margins (\$ ha^{-1}) for strategies 1-7 at 10, 12, 14 and 16 SU ha^{-1} (italicised values in parentheses are coefficients of variation)

Strategy[1]	SR (SU ha^{-1})			
	10	12	14	16
1	560.56 *(13.47)*	701.91 *(14.58)*	810.56 *(16.26)*	1043 *(19.58)*
2	626.33 *(17.50)*	801.83 *(16.90)*	972.97 *(17.92)*	1064.23 *(19.57)*
3	672.61 *(16.16)*	723.22 *(15.84)*	849.42 *(16.42)*	1168.17 *(19.39)*
4	675.48 *(15.16)*	797.13 *(17.23)*	910.22 *(15.59)*	1172.95 *(18.15)*
5	646.34 *(14.98)*	763.04 *(15.55)*	825.86 *(16.28)*	969.86 *(19.95)*
6	668.18 *(15.32)*	814.81 *(15.10)*	827.32 *(15.78)*	1063.80 *(18.48)*
7	581.90 *(15.46)*	644.23 *(16.60)*	747.19 *(15.29)*	912.08 *(19.13)*

Figure 4.2 further shows annual GMs for the different strategies and stocking rates. The average GM is represented by the 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. This variability constitutes risk and comprises both a 'down-side' resulting from poor seasons and an 'up-side' resulting from good seasons. The vertical lines labelled A, B, C are used to separate the GMs based on SR to improve the graph visualisation only.

It is apparent from both Table 4.4 and Figure 4.2 that while there is some variability between strategies, in general as the SR increases from 10 to 16, there is both an increase in enterprise profitability (average GM) and an increase in risk. Strategy 2 at 10 SU ha^{-1} resulted in least profitability, the distance between the standing charges (denoted by SC in Figure 4.2) and the average GM (+ symbol). Conversely, strategy 4 at 16 SU ha^{-1} resulted in the highest average profitability relative to other strategies tested.

Figure 4.2: Gross margins for strategies 1-7 at 10, 12, 14 and 16 SU ha^{-1}

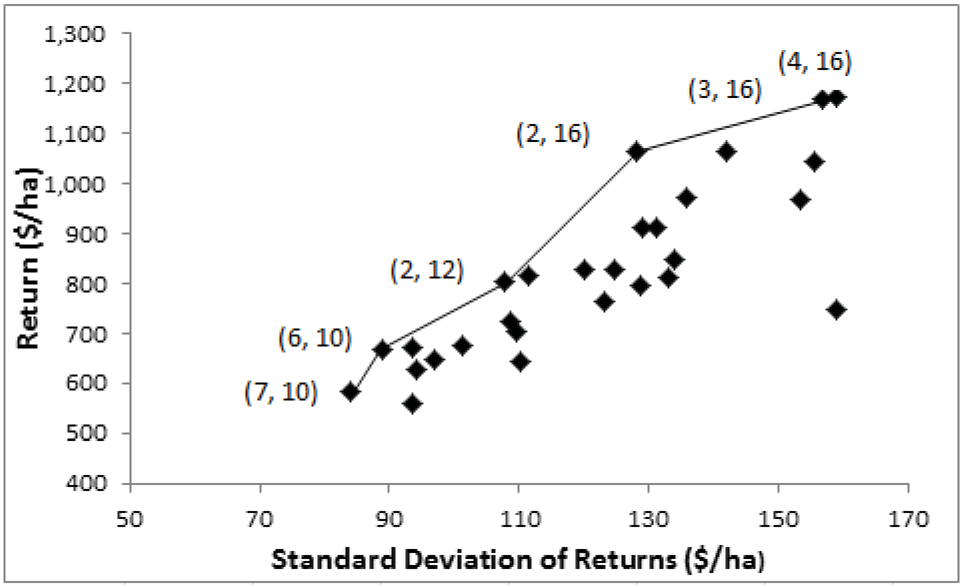


It is apparent that the variability of returns is not always symmetrical; in other words, the 'up-side' may exceed the 'down-side' risk or *vice versa*. It is also apparent that many of the strategies at all SR include years when returns over standing charges are negative. At SR 10 and 12, strategies 3 and 5 are exceptions, at SR 14, 2 and 7 are exceptions and at SR 16 most of the strategies make a profit despite having a greater variability in GM (greater risk).

There are clearly a range of positions a farmer may adopt in terms of the average return and variability of returns, even within the relatively restricted range of options considered here. Another way of viewing the results is to plot the scatter of returns vs risk (variability) for all combinations of strategy and SR. This is shown in Figure 4.3 which plots the average or expected GM for each strategy:SR combination against the corresponding standard deviation of returns. This allows identification of the 'risk efficient frontier' which shows the best possible combinations of expected GM and risk in relation to alternative policy options and stocking rates. Any combination which is not on the frontier is inefficient since a higher expected return may be obtained for the same level of risk by moving vertically to the frontier, or the same expected return may be obtained at lower risk by moving horizontally to the frontier.

Each point on the frontier represents a different combination of management policies and SR. Within the set of alternatives considered here, there are 6 risk efficient strategy combinations involving 5 different policies at 3 stocking rates, ranging from lower return-lower risk combinations to higher return-higher risk combinations. This gives farmers a range of farming policies to choose from which are all rational in the sense that they are risk efficient as defined above. The optimal choice for a highly risk-averse farmer would be the combination of strategy 7 at 10 SU ha^{-1}, that is a sheep-only policy with a relatively high proportion of high nutritive value pasture species at a stocking rate which is typical of the area. For a completely risk-indifferent farmer, that is one who is prepared to accept high risk-high return strategies, then strategy 4 at 16 SU ha^{-1} is the optimum choice. This is a mixed sheep and cattle policy with conventional pastures at a high stocking rate.

Figure 4.3: Expected returns (GM) vs Risk (SD of GM) for all strategies at 10, 12, 14 and 16 SU ha^{-1}, showing the risk efficient frontier



Chapter 5
Discussion

Most farmers are risk averse to some degree or other (Kingwell *et al.*, 1993). However, this does not mean that they are unwilling to take risks, rather that they must be compensated for taking the risk and that the compensation required must increase as the risk increases. This emphasises the value of the risk efficient frontier as a guide to producers on risk-return trade-offs which is better than simply considering whether an individual is risk averse or not.

The risk efficient frontier also provides some insight into the characteristics of the policy:stocking rate combinations which are rational choices. First note that as the risk and returns increase, so does the stocking rate; the low risk-low return combinations are at 10 SU ha^{-1}; intermediate risk-return combinations are at 12 SU ha^{-1} and high risk-high return combinations are at 16 SU ha^{-1}. Also as the risk-return combinations change, so does the farming policy. Strategies 1-4 are all conventional pasture systems with different stock policies while strategies 5-7 include increasing proportions of high nutritive value species. The high nutritive value pasture options appear at the low risk-low return end of the frontier. The intermediate and high risk-high return choices all involve conventional pasture systems, indicating that if the system is intensified, it is best to do so with a conventional pasture base.

A note of caution needs to be sounded here in that this analysis has been conducted for one location, meaning one set of climate values. Where climate is significantly different, for example in much drier areas, the same conclusions may not apply. The inability of conventional ryegrass:white clover pastures to survive in very low rainfall areas has been identified as one reason for moving to alternative pasture species which are more drought tolerant (Avery *et al.*, 2008).

Another way of interpreting the results is to say that at lower stocking rates, systems including high nutritive value species out-perform those that don't. This makes intuitive sense because at lower stocking rates, grazing is likely to be more lax and in these circumstances, legumes will retain their quality longer than grasses. With conventional pastures species, stocking rates need to be higher in order to maintain pasture utilisation and quality at a high level. This was one of the key elements of the grass unit at Silverwood as noted earlier in section 2 of this report. However, the results presented here suggest that it is more risk efficient to push the stocking rate higher to 16 SU ha^{-1} rather than use 14 SU ha^{-1} as in the trial.

Strategies 2, 4 and 6 all include cattle in their stock policies and these constitute 4 of the 6 risk efficient combinations. The other two, involving strategies 3 and 7 include a 1st cycle sheep mob. Thus these results confirm commercial experience that including a flexible stock class, either cattle or a buffer mob of sheep (or both), which are the first to be sold when conditions dry, is an essential feature of risk-efficient systems. Strategy 1 which includes a mixed age flock with no buffer mob of older ewes or cattle does not appear on the frontier at all. Neither does strategy 5 which is a sheep only policy, which does include a 1st cycle mob, with approximately 30 per cent of the property in high nutritive value pasture species

The results described here are premised on a policy of selling stock in response to drying conditions at a pre-determined and consistent point. The algorithm that controls this in the model is triggered by soil moisture level declining to 10 per cent, the level used in the Silverwood trial.

Once initiated, stock sales are determined iteratively as the season progresses depending on the severity of the situation at each assessment in terms of pasture availability and stock numbers, expressed as grazing days available (Gicheha *et al.*, 2013 a). More stock will be sold if the situation is classed as very severe and fewer if it is less severe. Responding in a different way, at a different time or to a different monitor variable would most likely change the risk-return characteristics of the strategies considered here. A more comprehensive analysis of risk responses is considered in Gicheha *et al.* (2013 b).

5.1 Conclusions

Results obtained in this study illustrate that a range of feed supply systems can be risk efficient, rational choices for farmers to implement. Published examples of different pasture systems include the combination of species investigated by Fraser *et al.* (1999) at Winchmore, sub-clover in the Awatere Valley (Grigg *et al.*, 2008), lucerne in coastal Marlborough (Avery *et al.*, 2008) and both grass-based and high legume systems at Hororata (Bywater *et al.*, 2011 a). In all cases, high pasture quality leading to high scanning percentages and high lamb growth rates has been identified as key elements of success. The results reported here are consistent with those findings.

Results suggest that feed supply systems including high nutritive value species perform best at the lower risk-lower return end of the risk efficient frontier at stocking rates typical currently in the study area. At the high risk-high return end of the frontier, conventional feed supply systems are the most risk efficient but at significantly higher stocking rates. In either case, maintaining a portion of stock as flexible stock classes such as two year old cattle or some form of buffer ewe mob which may be sold quickly once conditions dry out is essential to achieving consistent results in a highly variable environment.

This analysis has been conducted using the same soil moisture trigger value for responding to dry conditions as used in the Silverwood trials. Other trigger values would be possible and these have been evaluated by Gicheha *et al.* (2013 b).

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