Appendix 3. Effectiveness of a range of grazing system adaptations in ameliorating the impacts of shorter growing seasons

Introduction

Modelling studies of pasture growth based on projections of future climate by different global circulation models (GCMs) commonly predict shorter growing seasons in southern Australia with higher winter growth rates. We have therefore undertaken a simulation study to identify potential strategies that may be adopted by managers of sheep enterprises in order to adapt to the effects of shorter, more intense growing seasons (SIGS).

This Appendix describes the development of a method for modifying historical weather records so that growing seasons start later and end earlier, and the use of this method in conjunction with simulation modelling to explore the effect of alternative management strategies on profitability of a sheep grazing enterprise subjected to shorter growing season, at a range of locations across southern Australia.

Methods

Locations

To identify advantageous management strategies that were applicable in a number of regions and under diverse conditions, we selected multiple locations for analyses. Locations were selected to fall within the seven ABARE regions with the highest total value of production from sheep enterprises (see the financial tables at www.abare.gov.au/interactive/agsurf/tables/08_09/Financials_TBL.xls). Within each region a single location was selected based on the availability of readily-available information about soils and pastures. The locations that were chosen were Hamilton (Vic), Goulburn (NSW), Wagga Wagga (NSW), Cowra (NSW), Katanning (WA), Lucindale (SA) and Mt Barker (WA)

Grazing system details and initial conditions

Grazing systems at each location were modelled using the GrassGro decision support tool (Moore *et al.* 1997). A common livestock enterprise (Merino ewes producing first-cross lambs) was simulated at all seven locations in order to simplify comparisons across locations. This particular system was selected as it is employed widely across southern Australia in both the high-rainfall and cereal-livestock zones. The baseline enterprise consisted of medium Merino ewes (standard reference weight 50 kg) crossed with Dorset rams, with lambing on 21 April and weaning on 21 July. Ewes were mated for the first time at 18 months of age. Excess young ewes and wethers were sold between 1 September and 31 January (i.e. aged 18-40 weeks) once their average weight change over the preceding week fell below zero. Maintenance feeding was performed at any point during the year when the average condition score of animals in an age class fell below 2.0. Ewes and any remaining lambs were shorn each 30 November. Six-year-old ewes were sold on 30 November and immediately replaced by purchased ewes (17 months, condition score 3.0).

Both autumn and spring lambing dates were considered while these modelling analyses were being designed. In the end we chose to use a common (autumn) lambing date across all locations rather than location-specific lambing dates. Even though autumn may not be the most common choice of lambing date at all of the seven locations, it would be practiced by some graziers within each region. Also, preliminary simulations indicated that, for the cost and price assumptions used here,

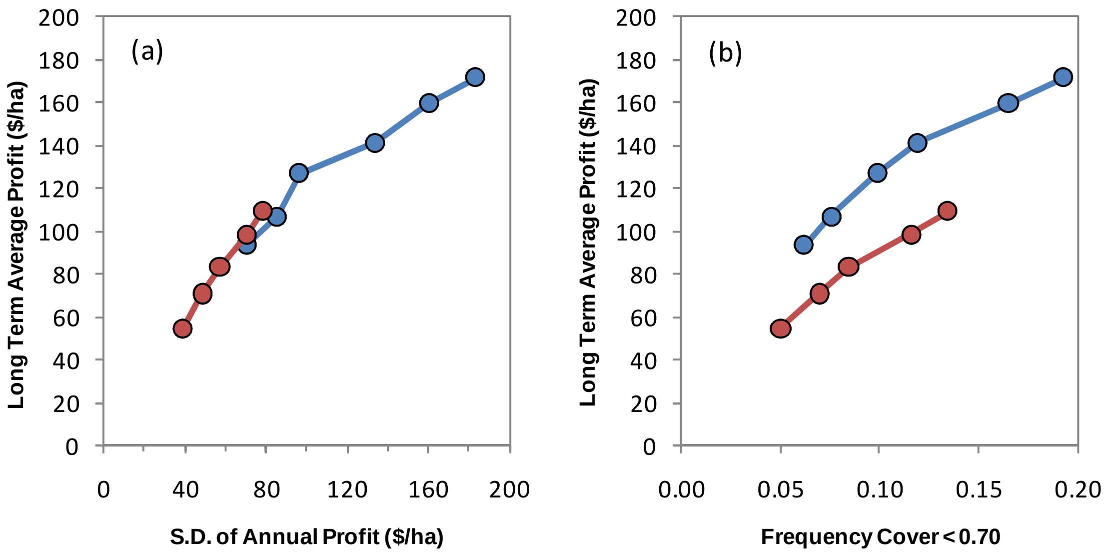

Figure A3.1. Profit versus risk in Merino ewe grazing systems at Wagga Wagga. (a) Long-term average profit versus long-term average standard deviation of annual profit at and (b) long-term average profit versus the frequency with which ground cover i below 0.70. Blue curves are for ewe grazing systems with April lambing and red curves are for July lambing. Points are mean values of 30 years simulated using historical weather records from 1970-1999 at a range of different stocking rates.

the long-term expected profitability of autumn-lambing systems was higher at all seven locations at equal levels of frequency of low ground cover (see Figure A3.1 for an example). On balance, therefore, it was decided to use a common (April) lambing date.

The costs and prices given in Appendix 1 for medium-wool Merino ewes were used to compute financial returns. Pasture management costs were based on fertility scalars, which in turn were determined by incremental fertiliser applications as described by Quigley *et al*. (2003). All fertilisers were assumed to be diammonium phosphate and were priced at $500 per tonne following values given by the Fertiliser Industry of Australia Incorporated. Overhead costs of $100/ha were assumed at all locations.

For each grazing system and adaptation option considered, an "optimal sustainable" stocking rate was then identified as that rate which maximized long-term profit, subject to the constraint that ground cover (averaged over the farm) should be less than 0.70 on no more than 7% of days over a 30-year period. This rate was found by simulating stocking rates in increments of 0.5 or 1.0 ewes/ha and selecting from these rates the one that met the criterion.

Manipulating baseline weather records to produce shorter growing seasons

We produced artificial weather records that would consistently shorten growing seasons but produce greater winter growth rates when simulated using GrassGro. To make the contraction of growing season uniform across sites, weather records were iteratively modified so the reduction in total annual net primary productivity (NPP) from baseline conditions was approximately 10%. The general approach was to (i) "squeeze" the rainfall events corresponding to each year's growing season into a smaller period of time, while carrying the variation in temperature and radiation corresponding to each sequence of wet and dry days along with it; (ii) increase temperatures by a fixed amount; and (iii) increase the atmospheric CO_2 concentration.

The following describes the procedure used to modify baseline weather records to produce SIGS for each site in attempt to produce artificial weather data that were representative of 2030 conditions.

1. Baseline weather records were obtained as Patched Point Datasets (PPDs) from the SILO database (http://www.longpaddock.qld.gov.au/silo, verified 25 October 2010).
2. Using the initial conditions specified and optimal stocking rate for historical weather conditions (identified in preliminary simulations), the earliest, median and latest dates of 'start' and 'end' of growing season were determined from the 30 years simulated at each site.
3. A function was defined that defined the number of days a given day-of-year should be shifted in time so as to shorten the growing season. This function increased linearly from zero on the day-of-year of the earliest growing season start until the median growing season start, then declined linearly to zero on the day-of-year of the latest growing season start. Similarly, the function decreased linearly (i.e. a negative shift in time) from zero on the day-of-year of the earliest growing season end until the median growing season send, and then increased linearly back to zero on the day-of-year of the latest growing season end. Where possible break and end contractions were made uniform but within the constraint that no original day from the baseline was mapped to more than six days on the SIGS weather record.
4. Cubic splines were fitted to long-term average records of maximum and minimum daily temperatures and the clearness index (ratio of radiation at the ground surface to radiation reaching the top of the atmosphere) for wet (rainfall greater than zero) and dry days.
5. Using the long-term values computed in step 4, weather anomalies were computed.
6. All weather anomalies were mapped to an interval defined by the shifting function determined in step 3. This time interval was greater than 1 day when the shifting function was increasing and vice-versa.
7. Daily maximum and minimum temperatures for the SIGS weather records were calculated long-term average for the shifted date plus the temperature anomaly plus 2^oC. Uniformly increasing the temperature on all days of each year enhances pasture growth rates but also hastens phenological development leading to earlier senescence, producing the desired effect of shorter but more intense growing seasons.
8. Daily rainfall and clearness index data for the SIGS record were determined by summing or averaging the result back into daily intervals. Maximum and minimum temperatures for the SIGS record were determined from the baseline day that contributed the largest share to the transformed day.
9. Finally, SIGS records were produced by adding the anomalies back to long-term historical records. Modified Penman-Monteith equations as described by the FAO (Allen *et al.* 1998) were used to compute corresponding daily vapour pressure and pan evaporation values.

All simulations of SIGS were run with an assumed atmospheric CO_2 concentration of 450 ppm. This higher CO_2 concentration increased the modelled radiation and water use efficiencies during the growing season.

There is no generally-accepted method for defining the start and end of growing seasons. In this work, the start of each growing season was defined as the date when total available green dry matter (AGDM) became greater than 500 kg/ha and daily pasture growth rates were 1 kg/ha or greater. The end of each growing season was defined as the date when total AGDM became less than 100 kg/ha. End dates were allowed to occur as late as 31 March of the following year (whereupon the following growing season was initiated if 'start' conditions were also satisfied).

By design, the SIGS weather time series had the same total rainfall in each year of the record (and hence the same rainfall variability), but with rainfall concentrated into a shorter period in autumn through to spring. Temperatures and evaporation rates were higher and radiation amounts were generally similar.

The maximum shifts applied to growing season start dates ranged from 10.5 d at Wagga to 52 d at Katanning, and shifts applied to end dates ranged from 5 d at Hamilton to 38 d at Katanning (Table A3.1).

Table A3.1. Median start and end dates identified from growing seasons simulated at the seven sites examined, and corresponding shifts applied to median dates to reduce total net productivity by approximately 10%.

Site	Median start of growing season	Shift applied to start dates (days)	Median end of growing season	Shift applied to end dates (days)
Hamilton	18 Feb	30	31 Dec	5
Goulburn	26 Mar	25	23 Dec	25
Wagga	28 Apr	10.5	24 Nov	10.5
Katanning	13 May	52	17 Nov	38
Cowra	7 Apr	27	17 Dec	27
Lucindale	26 Apr	40	22 Jan	26
Mt Barker	30 Apr	26	31 Dec	30

Adaptation options

The adaptation options to be tested were determined via a survey of state-based managers, industry representatives and scientists in the *Southern Livestock Adaptation 2030* program. Participants were asked to rank management changes in the order they believed that would be most likely to be implementable as adaptation options. This approach enabled a prioritisation of strategies that would have the greatest likelihood of being implemented by producers in the short-term.

Adaptation strategies examined included:

1. *Confinement feeding*: Between 1 November and 1 August in the following year, all livestock were removed from paddocks when total available dry matter fell below a threshold mass and were put back onto fields when AGDM became greater than 400 kg/ha. Sheep in feedlots were fed a supplement that was sufficient to maintain live weight *ad libitum* (as ewes were generally pregnant during confinement feeding, the quality of this supplement was quite high). No confinement feeding was performed under baseline conditions. Three variants of this option were examined:
   - start feeding when AGDM fell below 2000 kg/ha;
   - start feeding when AGDM fell below 1500 kg/ha;
   - start feeding when AGDM fell below 500 kg/ha.

2. *Joining time and age:* Several combinations of joining time (1 Nov and 1 Dec) and age at first joining (6, 18 or 30 months) were considered, following Young *et al*. (2010) who showed that modification of joining times and ages of first-cross lamb enterprises had large effects on profitability. Conception rates of single and twin lambs were adjusted according to joining time and latitude of each site using the equations given by Freer *et al.* (1997), assuming a joining period of 6 weeks. The base scenario used 1 Nov mating and first joining at 18 months. Five variants were examined:

- 1 Nov mating, first joining at 6 months;
- 1 Nov mating, first joining at 30 months;
- 1 Dec mating, first joining at 6 months;
- 1 Dec mating, first joining at 18 months;
- 1 Dec mating, first joining at 30 months.

3. *Earlier-maturing annual grasses:* The effect of adding early-maturing annual grasses to the pasture sward was also examined, to test the hypothesis that production of more forage at earlier times of the growing season via an earlier-maturing genotype would extend the period of adequate cover during summer-autumn and also reduce the need for supplementary feeding. Two varieties of annual grass were considered:
   - the standard "early annual grass" parameter set, corresponding approximately to barley grass (*Hordeum leporinum*)
   - a hypothetical "very early annual grass" that was constructed by adjusting the parameter set for "early annual grass" to make the onset of reproductive growth, flowering date and developmental senescence earlier.

4. *Increasing pasture fertility:* Modifications to pasture fertility were examined since future climates will effect plant tissue concentrations of photosynthetic enzymes (primarily protein dilution) but may also affect stomatal conductance (affecting leaf water loss and evaporative cooling) and overall pasture water-use efficiencies. Corresponding increases required in fertiliser applications were adapted from the data specified by Quigley *et al*. (2003) (Table A3.2). One variant was considered:
   - increase the baseline fertility scalar by 0.10 units at each location.

The sustainable optimal stocking rate under SIGS conditions was re-estimated (using the methods described above) with each of the adaptation options in place. All results compare grazing systems at their sustainable optimal stocking rate.

Table A3.2. Data from Quigley *et al*. (2003) for mean annual pasture production at different fertiliser application rates, corresponding GrassGro fertility scalars and associated prices specified as annual pasture costs

Fertiliser applied (kg/ha/year)	GrassGro fertility scalar (-)	Pasture costs ($/ha/year)
11	0.43	6
45	0.47	23
90	0.62	45
130	0.78	65
170	0.84	85
260	0.86	130
375	0.86	188

Results

Effect of shorter growing seasons on gross margins

Long term average annual profit under historical weather conditions ranged from $520/ha at Hamilton to $102/ha at Wagga Wagga. Profits were primarily governed by allowable stocking rates, which were determined by the interaction of the minimum ground cover constraints, the climate and the soil fertility at each location (Figure A3.2).

Under a business-as-usual scenario, SIGS may decrease gross margins in most regions of southern Australia. However, it should be cautioned that the margin of variability associated with mean gross margins predicted under SIGS is well within the variability of current conditions (Figure A3.2), so effects of warmer, drier conditions forecast to occur by 2030 may not be significantly detrimental to southern grazing systems. At Hamilton, Goulburn, Wagga and Katanning, the variability of gross margins under SIGS was similar to historical conditions. In contrast, long-term variability declined at Cowra, Lucindale and Mt Barker suggesting that annual total income at these locations may become more uniform under future conditions.

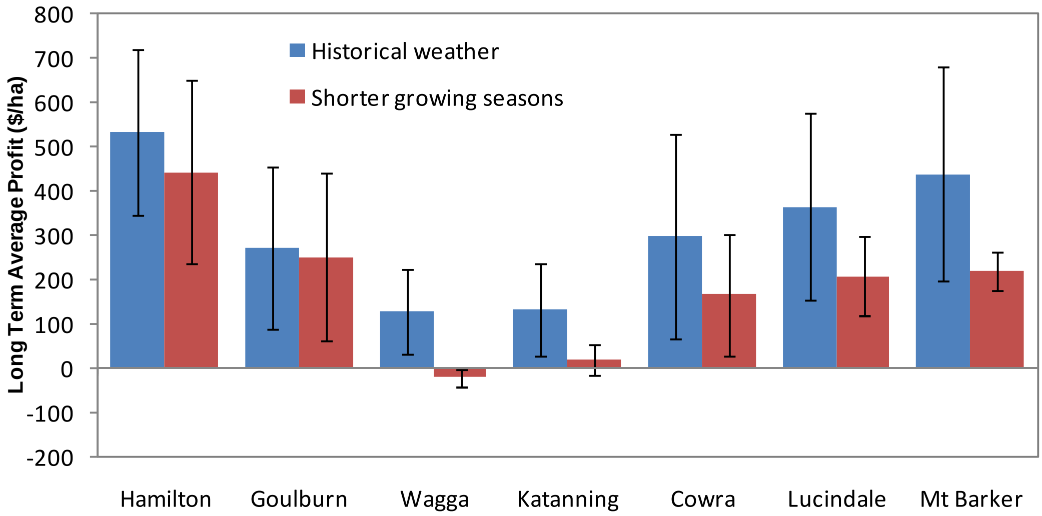

Figure A3.2. Long-term average annual profit modelled for Merino ewe enterprises producing first-cross lambs under historical (1970-1999) and shorter growing seasons at the seven locations. Error bars are ± one standard deviation.

Effects of shorter growing seasons on profit relative to historical baselines with alternative adaptation strategies

The effects of SIGS on long-term average profitability relative to historical baselines are shown in Table A3.3. Adaptation options shown in green in Table A3.3 indicate that the effects of shorter growing seasons may be mitigated by the intervention. Values in red imply that those changes to management would be detrimental to profitability under shorter growing seasons.

At Hamilton, several adaptation options were relatively capable of mitigating the effects of SIGS. Confinement feeding and sowing of early annuals were amongst the most advantageous (Table A3.3). Changing mating time to a month earlier (November cf. December) had a very small positive effect, while an older age at mating had a small negative effect. At the fertilizer prices and application rates assumed, increasing pasture fertility through increasing fertiliser application at Hamilton under future climates appeared to reduce gross margins slightly.

At Goulburn, beginning confinement feeding when total available dry matter fell to levels of 2000 or 1500 kg/ha was shown to be beneficial relative to the business-as-usual option (Table A3.3). In contrast to Hamilton, increasing pasture fertility may increase profitability at Goulburn under SIGS.

Table A3.3. Relative change in long-term average annual profit after undertaking each of a set of adaptation options under shorter growing seasons, relative to a 1970-1999 historical baseline with no adaptation, at seven locations across southern Australia. Cells shaded in green denote an improvement of 2% or more relative to no adaptation under shorter growing seasons (i.e. the values in the first row); cells shaded in red denote a decline in profit of 2% or more relative to no adaptation under shorter growing seasons.

The baseline scenario from which each adaptation option departs includes no confinement feeding; 1 Dec mating, first joining at 18 months; no additional annual grass in the sward; and standard fertility scalars (mostly corresponding to moderate soil fertility) at each location. Profit of each grazing system is compared at its sustainable optimum stocking rate, as defined in the text.

Adaptation option	Hamilton	Goulburn	Wagga Wagga	Katanning	Cowra	Lucindale	Mt Barker
No adaptation (except stocking rate)	-0.16	-0.08	-1.17	-0.85	-0.44	-0.43	-0.50
Confinement feeding, threshold to start 2000 kg DM/ha	-0.06	-0.01	-0.96	-0.98	-0.30	-0.45	-0.32
Confinement feeding, threshold to start 1500 kg DM/ha	0.00	+0.04	-1.02	-0.89	-0.39	-0.41	-0.42
Confinement feeding, threshold to start 500 kg DM/ha	-0.16	-0.09	-1.17	-1.02	-0.45	-0.43	-0.50
1 Nov mating, first joining at 6 months	-0.14	-0.09	-1.24	-0.91	-0.50	-0.53	-0.57
1 Nov mating, first joining at 18 months	-0.15	-0.08	-1.24	-0.91	-0.43	-0.53	-0.55
1 Nov mating, first joining at 30 months	-0.15	-0.09	-1.24	-0.91	-0.51	-0.53	-0.55
1 Dec mating, first joining at 6 months	-0.17	-0.08	-1.16	-0.85	-0.44	-0.43	-0.42
1 Dec mating, first joining at 30 months	-0.18	-0.06	-1.24	-0.93	-0.41	-0.52	-0.57
Early annual grass added to the pasture	-0.12	-0.06	-1.15	-0.84	-0.42	-0.46	-0.42
Very early annual grass added to the pasture	-0.14	-0.07	-1.35	-0.99	-0.42	-0.44	-0.46
Increased pasture fertility	-0.18	-0.02	-1.16	-1.05	-0.48	-0.46	-0.49

At Wagga Wagga and Katanning, shorter growing seasons sufficient to decrease NPP at Katanning by 10% were forecast to decrease average annual profit by 117% and 85% respectively. At Wagga Wagga, confinement feeding with a total available dry matter threshold of 2000 or 1500 kg/ha was the only adaptation option that moved profitability back toward historical levels to any extent, while at Katanning none of the trialled adaptation options was effective (Table A3.3). Results at Lucindale were generally similar to those at Wagga Wagga, except that the general level of profit decline under SIGS was smaller.

At Cowra, confinement feeding to higher dry matter thresholds somewhat reduced the effects of SIGS on gross margins. Shifting ewe joining times to a month earlier generally had negative effects on profitability due to the additional requirement for supplementary feed.

For Mount Barker, a number of adaptation options (including confinement feeding to higher dry matter thresholds, earlier joining and the addition of earlier-maturing annual grasses to the pasture) had some effect in reducing the impact of SIGS.

Generality of adaptation options across sites

Confinement feeding was the most generally applicable adaptation option; starting confinement at a threshold of 1500 kg/ha improved profit at 6 of the 7 locations. Using a threshold of 500 kg/ha, on the other hand, was an ineffective adaptation option; presumably by the time dry matter reached this level, a period of low ground cover was guaranteed by further DM decay.

Adding early (or very early) annual grass to the pasture improved profit by at least 2% of historical levels at 3 of the 7 locations (Hamilton, Cowra and Mount Barker); adding early annual grass had a smaller but positive effect at 3 further sites.

At the prices assumed, neither the mating time options nor increasing pasture fertility were effective adaptation options for dealing with shorter but more intense growing seasons.

<u>Discussion and conclusions</u>

Production of artificially shortened growing seasons

The method used to shorten growing seasons was implemented for the seven sites, and was capable of reducing total net primary productivity (NPP). However the approach of requiring a 10% reduction from baseline productivity at each location needs revision. Alternative approaches could be to uniformly contract the growing season (e.g. to define a set number of days to modify the breaks and ends of the season), or better, contract growing season length by a common proportion rather than total productivity. Nevertheless, the method developed in this study will be useful for further studies of shorter growing seasons of predicted conditions beyond 2030 since manipulation of historical records to a desired level is straightforward, rapid and conducive to iteration.

Which adaptation strategies will be most beneficial under future climates?

The diversity of climates across southern Australia mean that there is no universal change to management that will be potentially advantageous under future conditions. Table A3.3 indicates that multiple management adaptations could be advantageous at locations with relatively longer growing seasons, such as Hamilton, Goulburn and Mount Barker. Adaptation strategies at sites with relatively short duration seasons such as Lucindale and Katanning appear more limited. Indeed, no adaptation strategy tested at Katanning appeared to be better than outcomes projected to occur by adapting stocking rates only.

Most reductions in profit were a result of the necessity to reduce stocking rates to meet the minimum ground cover constraints. Incorporation of pasture species more resilient to removal by livestock may represent a strategy to overcome the minimal cover requirement and thus increase SRs. Strategies that allowed the greatest resting of pastures (e.g. confinement feeding with a high threshold) were generally most beneficial, since they allowed recovery of pasture growth and restoration of ground cover. Future investigation of strategies preserving or increasing ground cover would likely prove beneficial.

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