‘Biophysical and economic impact and adaptation options in a changing climate for low rainfall mixed farms in southern NSW’

Final Report LA1948

Part 1
Baseline and projected biophysical and economic performance of 3 mixed farms in the Riverina and Central West Local Land Services regions

Part 2
Evaluation of 3 adaptive management strategies on 3 mixed farms in the Riverina and Central West Local Land Services regions

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Contents

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Executive summary

In order to assess the potential impact and adaptation options for mixed farms in the low rainfall zone of southern NSW, representative farm simulations have been developed for 3 sites in central NSW. Baseline biophysical and economic performance for each site has been established using the AusFarm modelling platform and their sensitivities to future climate scenario's for the period 2030 assessed using a series of economic, production and natural resource indicators. Results suggest that the 3 mixed farming systems selected for analysis are indeed sensitive to projected changes in climate and atmospheric concentrations of CO_2. The farms were differentially affected with the warmer drier sites at Goolgowi and Condobolin being negatively impacted but the relatively cooler wetter site at Temora positively impacted.

Across the 3 GCMs the average impact of the projected change for the Goolgowi and Condobolin sites included a;

- slight to moderate decrease of economic return across the two farms,
- a slight decrease in crop yield at least in part driven by a shortening of the growing season (exception being barley),
- decrease in annual pasture dry matter production and a slight change in seasonality at the 2 sites,
- moderate increase in the amount of animal supplementation required to meet livestock requirements,
- decrease in ewe body weight and condition score, and
- a decreased number of weaned lambs and lower average condition.

Across the 3 GCMs the average impact of the projected change for the Temora site includes a;

- slight increase in the economic return across farm,
- a slight increase in crop yield likely driven by increase CO_2 levels and decreased water logging,
- a slight shortening of the growing season,
- a slight increase in annual pasture dry matter production,
- slight decrease in the amount of animal supplementation required to meet livestock requirements,
- increases in ewe body weight and condition score, and
- an increased number of weaned lambs and better average condition.

An integrated assessment of 3 potential management strategies or adaptation options were made for each of the 3 sites. Options assessed included;

a. not sowing crops in years where rainfall conditions are not met at the conclusion of multiple sowing windows,

b. enhancing terminal lamb growth rates to shorten turn off period, and

c. lowering the minimum pasture cover threshold at which stock are moved to reduce livestock supplementation.

Results suggest that the negative impacts on biophysical and economic performance at the Goolgowi and Condobolin sites from the future climate scenarios can in part be countered by, altering triggers for sowing and improving animal genetics. The Temora site by contrast was negatively affected by altering the traditional sowing rule and only had a small positive response from improving animal genetics compared to the other sites. Lowering the minimum pasture cover threshold at which stock are moved offered no significant advantage at any of the sites.

Background

Extensive dryland agricultural systems are exposed to and dependent on the vagaries of the weather and are inherently sensitive to climate variability and change. The long term maintenance of farm productivity growth is a major priority for the NSW Government. The NSW agriculture sector contributes more than $14.5 billion or 3.4% annually (Fogarty *pers comm* 2014) to the state's economy, unfortunately there has been a significant slowdown in agricultural productivity in the broadacre sector since 1990, which can be partly explained by the effects of the Millennium drought. However uncertainties remain about the long term viability of the dryland agriculture sector in a changing but variable climate, particularly in the low rainfall zones (LRZ) of inland NSW.

Scope of this report

This project had its genesis at a time of significant change for its two partner organisations; the NSW Department of Primary Industries (NSW DPI) and NSW Local Land Services (NSW LLS), formerly known as the NSW Catchment Management Authority. Under a former government directive LLS's were to review their strategic plans for their catchment referred to as their Catchment Action Plans and to make those plans 'climate change ready'. The rationale being that some insight into the impact of projected change and viable adaptation options would enable the organisation to more readily facilitate change and increase catchment resilience over the longer term.

The aim of this report is to:

- provide an initial assessment of impacts of climate change on representative sites, and
- investigate the potential of a number of adaptation options to reduce the biophysical and economic impacts of climate change.

The work does not provide a comprehensive assessment of the adaptive capacity of farms in the region however the information is a valuable start to enable the LLS to engage producers in the region, as a way of developing their own adaptations and increase their resilience to climate stresses.

NSW DPI had demonstrated competence in conducting such investigation through 2 former national impact assessment projects funded by the former Department of Agriculture Fisheries and Forestry (DAFF) entitled; 'Developing climate change resilient cropping and mixed cropping/grazing businesses in Australia' and the 'Climate change adaptation in the southern livestock industries' (SLA 2030). Results from this work suggested that there was significant opportunity through incremental adaptation of farming systems however little was known about the potential impact of projected changes in climate on mixed farming systems in the lower rainfall zones (LRZ) of less than 350mm growing season rainfall in southern NSW.

Biophysical models

Farming systems by their very nature are incredibly complex. Traditional agricultural research in the field and laboratory has over time enabled mathematical relationships to be determined which through refinement have been built into agricultural computer simulations referred to as biophysical models. Whilst there is a range of sector specific models available, typically they simulate the effects of the environment and management decisions on agricultural production, profits and the environmental variables. In previous projects NSW DPI has favoured the Agricultural Production Systems Simulator (APSIM) (Keating B.A *et al* 2003, McCowan R.L *et al* 1995) for cropping research and GrassGro™ (Freer M *et al* 1997, Moore A.D *et al* 1997) for livestock systems work. In order to assess the impact of changes to climate on mixed farms, components of both the APSIM and GrassGro models were needed, CSIRO's AusFarm™ model (Moore A.D *et al* 2004,2007,2014)_enables integration of these and additional functionality, specifically the ability to represent the management structure and decisions in complex mixed farms. Biophysical models make no account of plant and animal disease or pest impacts and as such tend to optimise biophysical performance. A full description of each of the models can be found in Appendix 1.

Methods

Site selection

To explore the potential impact of projected changes to mixed farming systems in the low rainfall zone of NSW, sites were selected at Goolgowi and Temora in the Riverina LLS and Condobolin in the Central West LLS region. This site selection illustrated in Figure 1 has been based on a;

1. spatial analysis of April-October rainfall isohytes within the LLS region,
2. the availability of underpinning soil and historic climate data, and
3. LLS site nomination.

This selection of reference sites provides an ideal rainfall analogue from which to make assumptions about impact and adaptation in low rainfall mixed farming and grazing systems across the broader Riverina and Central West LLS areas. This project is being run concurrently with similar projects in the Western, Murray and Riverina LLS regions and those sites have also been included in Figure 1.

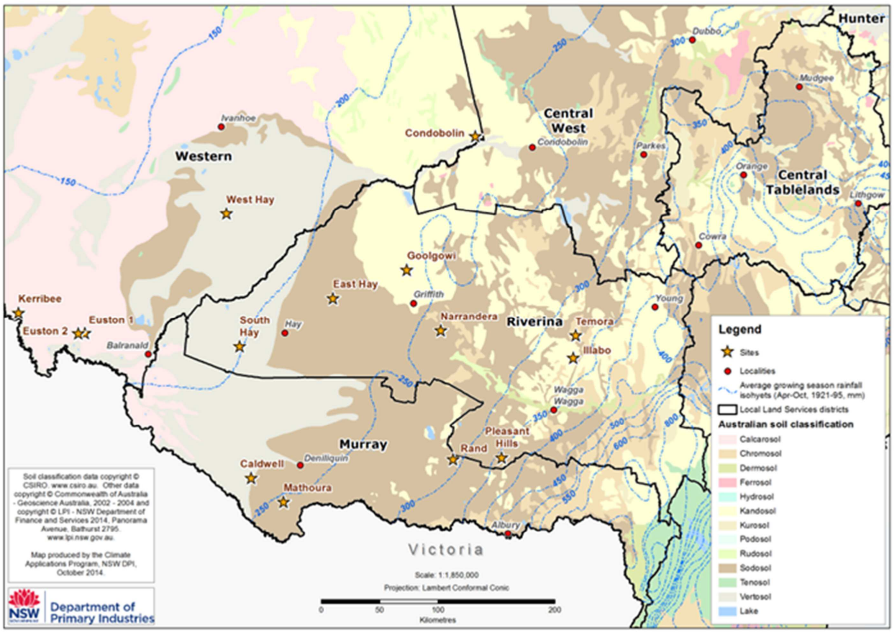

Figure 1. Reference mixed farms sites across the Southern NSW LLS regions

AusFarm setup

Soil characterisation

Simulations in AusFarm are underpinned by appropriate site soil characterisation data including drained upper and lower water capacity limits. An initial spatial review was undertaken of the existing soil data across the LLS region using the Australian Soil Resource Information System (ASRIS) www.asris.csiro.au site. Unfortunately due to limitations in data availability only a single soil type was used on each reference farm. A full descriptor of each site was determined using the ApSoil database http://www.apsim.info/Products/APSoil.aspx. A brief summary can be seen in Table 1 and a more detailed summary of soils at the 3 sites can be found in Appendix 4.

Table 1. Underpinning soil data for regional case study

Location	Latitude	Longitude	Soil Descriptor	PAWC Wheat
Goolgowi	34.03	145.99	Griffith Goolgowi No 697 (Sandy loam over sandy clay loam)	165mm
Temora	34.54	147.56	Temora No 179 (Brown chromosol)	131.4mm
Condobolin	33.00	146.63	Condobolin No 690 (Sandy loam over sandy to light clay)	125mm

Climate (baseline)

The AusFarm model is also dependent upon daily time stepped climate data. Historic daily climate data in the APSIM format is available through the Queensland Department of Science, Information technology, Innovation and the Arts (QSITIA) via its Longpaddock website, (http://www.longpaddock.qld.gov.au/data). The data available is either actual station data referred to as Patched Point Data (PPD) or as synthetic data which is derived from nearby stations referred to as Data Drill (DD). Given the variation in spatial density and distance of the LLS reference study sites to meteorology stations, Data Drill was determined to be the most representative method. DD accesses grids of data interpolated from point observations by the Bureau of Meteorology. The data in DD are synthetic; there is no original meteorological station data left in the calculated grid fields. Historic climatic data for the baseline period (1957-2012) for each case study site was used to derive baseline biophysical performance.

Farming system verification

In order to assess the impact of projected changes to the 3 mixed farms along the study transect it was necessary to build AusFarm farming system simulations which are representative of those at each study site. This is a resource intensive process where regional extension staff from LLS, who have detailed insight into farm systems management and performance, partnered with, departmental agricultural technical specialists and technical model developers to review the relevant literature (Appendix 2) and help refine the farming systems. Emerging from this consultation has been a series of underpinning assumptions that have been used for the development of case study sites at: Goolgowi, Temora and Condobolin. Table 2 summarises the farming system assumptions used to create the 3 reference farms. A more complete description of the 3 farms can be found in Appendix 3. The logic and accuracy of model coding for each site was inspected carefully by developers in consultation with regional staff. The output from a broad range of variables was assessed to ensure that management routines were performing satisfactorily, and there were no un-anticipated interactions as the routines became more complex.

Model outputs of crop, pasture and animal production were carefully assessed by regional staff to ensure that they were simulated within ranges typically obtained on farms in the region. Often this process involved up to 10 or more model refinements to ensure that the models performed acceptably. This level of acceptability testing, as opposed to formal model validation where independent measures are used, is typical practice in studies where the aim is to assess the sensitivity of a farming system to an external change like a shift in climate variability.

Table 2. Reference site assumptions

Site	Size	No Paddocks	Stock	Pasture	Crop
Goolgowi	4,000ha	8	Merino ewe * Dorset ram	Lucerne, Medic, Sub clover	Extended fallow, canola or wheat, wheat, wheat, barley, pasture (3 years)
Temora	2,000ha	10	Merino ewe * Dorset ram	Lucerne, Sub clover	Wheat, canola, wheat, barley, wheat, pasture undersown (5 years)
Condobolin	4,000ha	8	Merino ewe * Dorset ram	Lucerne, Medic, Sub clover	Extended fallow ,wheat, wheat, barley, wheat, pasture undersown (3 years)

The technical reference team engaged in developing the underpinning farming system design have subsequently been involved in the adaptation evaluation for the 3 site simulations in this phase of the project.

It should be noted that such simulations are dependent on the availability and quality of plant characterisation modules in the biophysical model with limitations on both species and cultivar data evident during this study.

Climate (projected)

Global climate is a system of energy exchange which is subject to different 'forcing processes' that influence its state. Global climate has and will continue to change in response to large internal forcing processes like the El Nino Southern Oscillation (ENSO) which influence year to year variability; external forcing events like major volcanic eruptions which influence global climate for 3-5 years; and much longer term forcing such as changes to the earth's orbit which have led to the glacial and interglacial cycles observed over tens of thousands of years. An important forcing process is the role of greenhouse gases in heat regulation of the atmosphere, and evidence that this has increased considerably over the last century as a by-product of fossil fuel use.

The combined effects of these forcing processes are studied intensively, leading to the strong expectation that the global climate will continue the warming trend over the coming century (Stefan et al 2011; AAS 2015; IPCC 2013; Reisinger et al. 2014), as part of this warming global average precipitation is also expected to increase on the whole, but with distinct regional variations. The expectation is major systems like the sub-tropical ridge of pressure which typically dominates the mid latitudes will intensify and move further south leading to reduced winter rainfall, by blocking rain triggering cold fronts from the south west. Inversely this broad scale synoptic change increases the chance of summer storms, by enabling moisture from the summer monsoons to penetrate further. (CSIRO 2010).

The combined effects of forcing are examined by tracking changes to weather and climate observations as well as Global Climate Models (GCMs). These models are based on the established laws of physics and have improved over time with the latest generation referred to as the CIMP5 models (Coupled Model Intercomparison Project) http://cmip-pcmdi.llnl.gov/cmip5/ . The GCM's also provide the opportunity to look forward and project what may occur over the coming 30 years into the future. There is moderate to high confidence in their ability to represent changes in global and regional temperature. However for rainfall there is reduced confidence beyond changes to the general global structure of rainfall patterns. For the Riverina LLS there is variability between different models in terms of how far south the sub-tropical ridge shifts or how far south the tropics expand over time. It is not uncommon for projections of rainfall from different GCMs to vary markedly when the results are examined at precise locations, such as an individual farm. For this reason this study follows the standard practice of considering multiple climate models as a way of providing a best estimate for anticipating changes which may take place in the future. In order to capture the range of plausible future climates across the LRZ of southern NSW, 3 CIMP5 GCM's were selected based on the M Skill Score assessment undertaken as part of the 2007 CSIRO and BOM assessment (CSIRO & BoM 2007). Arguably these 3 models quantify a range of possible climate outcomes in the RCP 4.5 emissions scenario. This selection illustrated in Table 3 enabled a range of likely plausible future climates to be explored and so avoids the issue around 'picking winners'.

Table 3. GCM selection for low rainfall mixed farming impact assessment

Modelling Institution	Model abbreviation used in report
Met Office Hadley Centre	'Hadley'
National Centre for Atmospheric Research	'CCSM'
Max Planck Institute for Meteorology	'Mon Plank'

Whilst there is significant uncertainty in predicting the future and indeed human behaviour and technological advances, a number of attempts have been made to standardise assumptions around providing a range of plausible futures. The Representative Concentration Pathways (RCP's) (IPCC 2014) are the latest attempt in this endeavour and supersede the previous Special Report Emission Scenarios referred to as the SRES (IPCC SRES 2000) which was used in previous NSW DPI impact assessment work. Figure 2 illustrates the relative radiative forcing from the various RCP's compared to the older SRES. Given the typical planning horizon of the agricultural sector, the period 2030 and RCP 4.5 were regarded as a realistic and useful point at which to examine the biophysical and economic impact of changes to climate and potential adaptation options for mixed farmers in the LRZ. As can be seen in Figure 2 there is minimal divergence at 2030 between all the RCP's and the SRES scenarios in terms of global emissions.

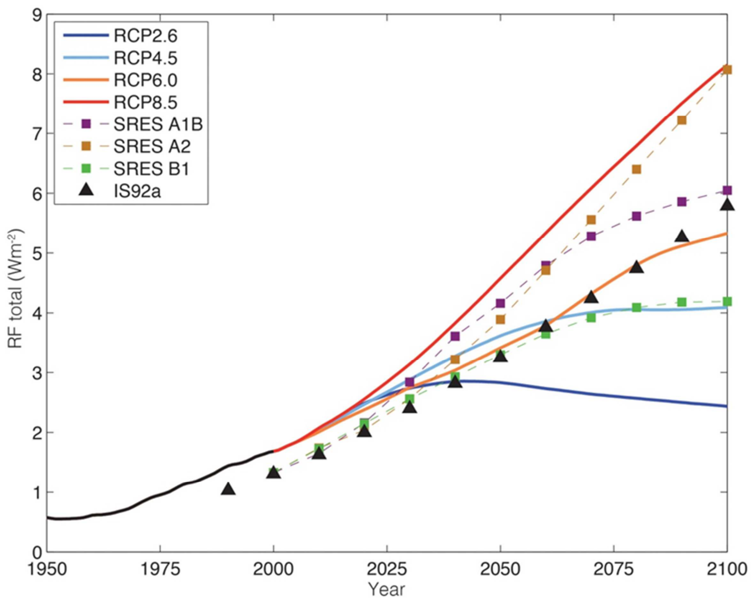

Figure 2.RCP and SRES trajectory comparison 1950-2100 (IPCC 2014)

It was initially proposed that CMIP5 projected climate data (Coupled Model Inter-comparison Project; http://cmip-pcmdi.llnl.gov/cmip5/index.html) would be sourced from the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA) via the Consistent Climate Scenarios delivery platform, unfortunately CMIP5 projected data from DSITA is yet to become available. A viable alternative was subsequently found, in a weather generator previously developed by CSIRO (Moore *et al* 2013) as part of the SLA2030 project. The weather generator uses daily historic climate for a site and modifies it based on GCM selection and RCP choice to produce a projected sequential daily weather dataset in a SILO format. This was then imported into AusFarm to examine site impacts.

CO_2 fertilisation

Throughout the 20th and 21st century atmospheric CO_2 levels have risen from preindustrial levels of ~280 (ppm) to their current levels of ~395(ppm). Under RCP 4.5, CO_2 levels are expected to rise further to 435(ppm) by 2030. The effect on both temperate (C_3) and tropical (C_4) plants of higher CO_2 concentrations is well documented and often referred to as the CO_2 fertilisation effect. Broadly speaking higher levels of CO_2 improve resource efficiency, productivity and plant production (Howden *et al* 2010) although the effect is dependent on photosynthetic pathway. The CO_2 fertilisation has been factored into the biophysical modelling, including feedbacks from the nitrogen and water cycle undertaken as part of this assessment of mixed farm in the LRZ of Riverina and Central Western LLS regions. The assessment has been made on the basis of levels of atmospheric CO_2 levels being ~435ppm in 2030.

Temporal boundaries

The objective of this project has been on the quantitative assessment of biophysical impact and adaptation options of mixed farming systems in the LRZ of NSW using CSIRO's AusFarm simulation model (http://www.grazplan.csiro.au/?q=node/3). This assessment by necessity has required an historic assessment of performance for the period 1957-2012 and a futuristic assessment under 3 climate scenarios centered on the year 2030.

Mixed farming enterprises rely on pasture production as a key part of the agronomic rotation within the system. Therefore, to ensure livestock numbers are maintained the AusFarm simulation has been set to feed animals at times of low pasture cover in either a feedlot or in the paddock (depending on seasonal conditions). To enable the simulation to establish pasture in the initial years and the animal system to reach a 'normal' state, a run in period of 7 years (period Jan 1950- Dec 1956) was used with biophysical output only reported for the period Jan 1957-Dec 2012 once pasture was established in the system. To enable AusFarm simulations of future climates to stabilise, the first 5 years of climate data (period Jan 2015 - Dec 2019) was used to initiate the system with biophysical output only reported for the following 26 years (period Jan 2020 - Dec 2045). The resulting output can be viewed as 26 potential realisations of weather for the year 2030.

Assessment indicators

Whilst there is a magnitude of output available from each farming simulation, limitations were applied to cap the number of critical indicators of performance for both the impact and adaptation assessments and so enable interpretation, common to both were the economic evaluation using gross margin analysis. The gross margin analysis provides a common metric across all systems and sites and was used as the overarching index to assess impact and adaptation response. The gross margins were derived from system and spatially relevant NSW DPI gross margins 2014 (http://www.dpi.nsw.gov.au/agriculture/farm-business/budgets) with biophysical output for each AusFarm simulation driving the economic analysis which was performed as post process in the statistical package 'R' (http://www.r-project.org/). It should be noted that gross margins are a simple representation of economic performance only taking into account variable income and costs and exclude overheads and any assessment of opportunity costs.

Impact assessment

It was determined that 9 indicators of farm performance provide an accurate assessment of baseline biophysical and economic response and the impact of a changing climate. The impact assessment variables used are shown in Table 4. To facilitate communication with stakeholders, the impacts across 3 GCM's are presented as either an average across the 3 GCM's or as a boxplot providing some sense of the distribution of outcomes. Details of this analysis can be found in Appendix 5.

Table 4. Key variables used to assess impact scenarios

Impact	Variables analysed
Climate	Annual rainfall Maximum and minimum temperature Winter/spring frost incidence
Economic	Gross margin farm Gross margin (crop/livestock)
Crop production	Crop yield Harvest date
Pasture production	Dry matter Ground cover
Livestock production	Supplementary feeding Ewe weight Lamb weight

Adaptation assessment

The 11 variables used (Table 5) in the adaptation assessment were chosen based on their capacity to summarise the gross impact of the adaptation option selected. As indicated it was determined that only those variables that directly related to each adaptation option would be included in the analysis.

The 3 agreed potential management strategies or adaptation options have been developed in consultation with advisory staff from the LLS partners. Options assessed are;

a. 'Sowing': The modelling work conducted for the impacts assessment allowed "dry" sowing to occur at the end of the sowing window if soil moisture triggers had not been reached (insufficient rainfall). The sowing adaptation strategy implemented ensures that crops are not sown in years where rainfall conditions are not met at the conclusion of multiple sowing windows.

b. 'Genetics': The modelling work conducted for the impact assessment ran a Merino ewe, terminal sire lamb production enterprise where the terminal sire (Dorset) had a reference weight was set at 80kg. The genetics adaptation strategy implemented increase the sire reference weight to 90Kg, in order to enhance lamb growth rates and shorten turn off period.

c. 'Cover': The modelling work conducted for the impact assessment was based on a pasture ground cover threshold of 50%. Once the pasture ground cover threshold was breached (cover fell below 50%), the animals were placed in a feedlot and provided supplementary feed. The cover adaptation strategy decreases this threshold by 5% in order to reduce livestock supplementation.

Table 5. Key variables used to assess adaptation scenarios

Adaptation	Variables analysed
Sowing	Gross margin for farm Gross margin for crop Crop yield Years no crop was sown
Genetics	Gross margin for farm Gross margin for animal Lamb performance Average days to lamb turn off
Cover	Gross margin for farm Minimum ground cover farm Supplementation levels to ewes

Interpretation of box plots

Box and Whisker plots are useful way of examining the distribution of a dataset. The plot illustrated in Figure 3 is split into quartile groups. The main 'box' section of the plot represents the results within the second and third quartile (50% of the data), while the horizontal line splitting the box represents the median value. The diamond represents the average value. The straight lines, 'whiskers', extending from the box represent the maximum and minimum values, excluding outliers, which are shown as '+'. When interpreting the plot, it is important to look at the distribution of the plot. For example, a shortening of the lower whisker (b) in a gross margin analysis infers that there is a decrease in the probability of receiving lowers end returns. Likewise, an increase in the top whisker (c) suggests an increased chance of hitting higher returns. The symmetry of the 'box' is also useful when interpreting the plot. The longer the 'box' (c), more variation in the results can be expected. If the box is skewed (a), the smallest quartile reflects more consistent results; whilst the large box shows a greater spread of expected outcomes.

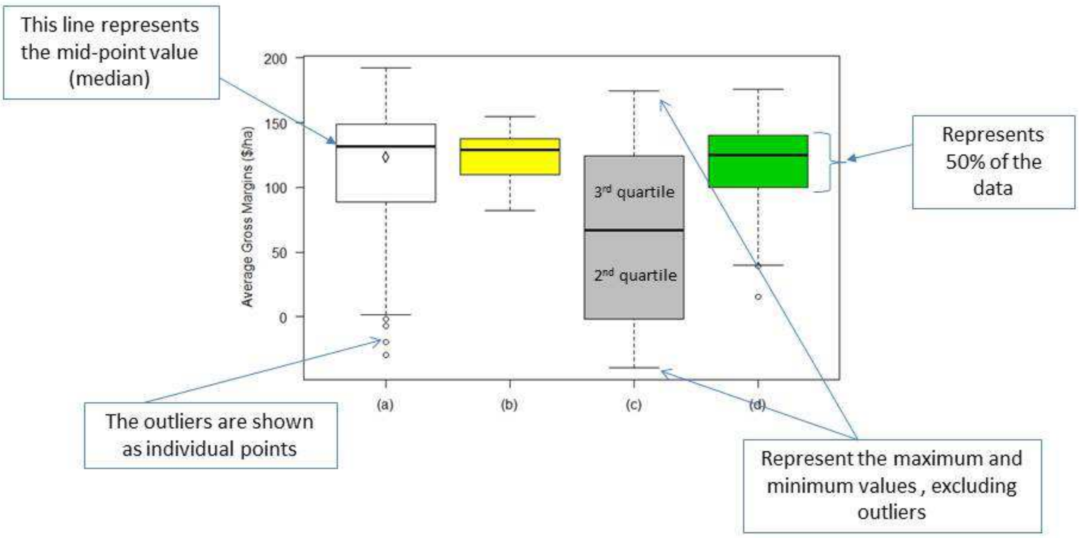

Figure 3. Boxplot interpretation

Results

Impact assessment – Goolgowi

Goolgowi climate

Figure 4, Figure 5 and Figure 6 show the comparison of historical and projected climatic conditions at Goolgowi. Figure 4 shows the range of potential rainfall compared to historical measurements. Figure 5 shows that there is an overall expected increase in both average maximum and minimum daily temperatures throughout the year, with increase of up to 2°C not uncommon. The occurrence and projected changes in winter/spring frost (Figure 6) shows a slightly higher probability of later season frosts. This increased incidence of later frosts has the potential of effecting crop performance. A more detailed monthly statistical analysis including an assessment of rainfall and maximum temperatures can be found in Appendix 6.

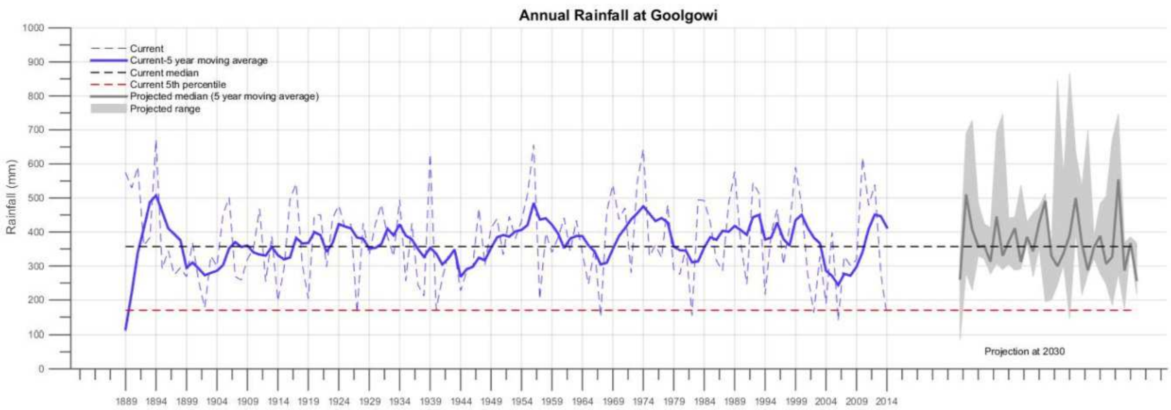

Figure 4. Long term variability in annual rainfall at Goolgowi with the range of climate model projections at 2030.

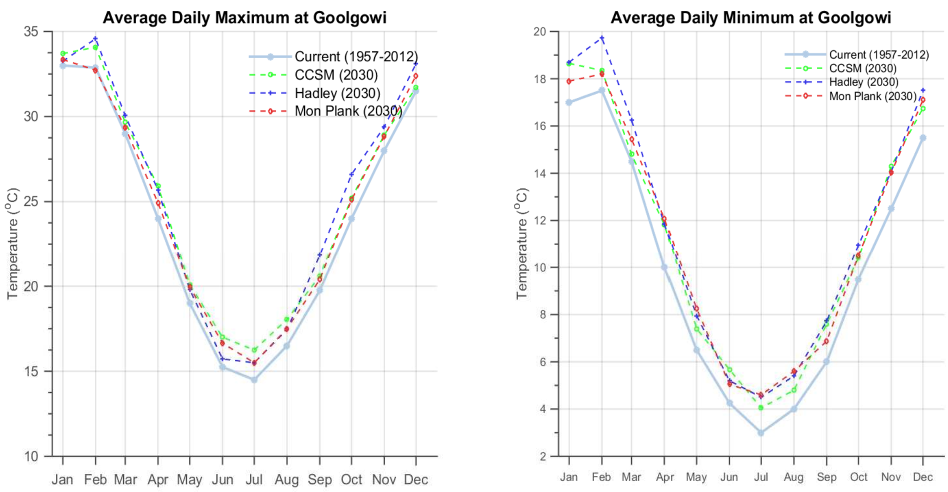

Figure 5. The maxima and minima monthly temperatures at Goolgowi for current climate and the projected period (2030).

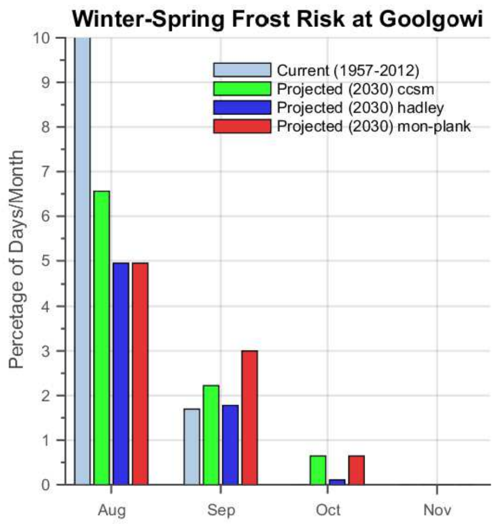

Figure 6. Late winter/spring frost risk at Goolgowi, where a frost is a minimum daily temperature below 0 degrees C.

Goolgowi economics

Figure 7 presents the gross margin calculations for Goolgowi for the animal, crop and whole farm component of the farming enterprise, comparing historic conditions to future climate scenarios (CCSM, Hadley, Mon Plank and a combined summary of the three GCMs). The data suggests that there will be a slight to moderate decrease in economic returns under future climate with the Hadley scenario being the worst performer.

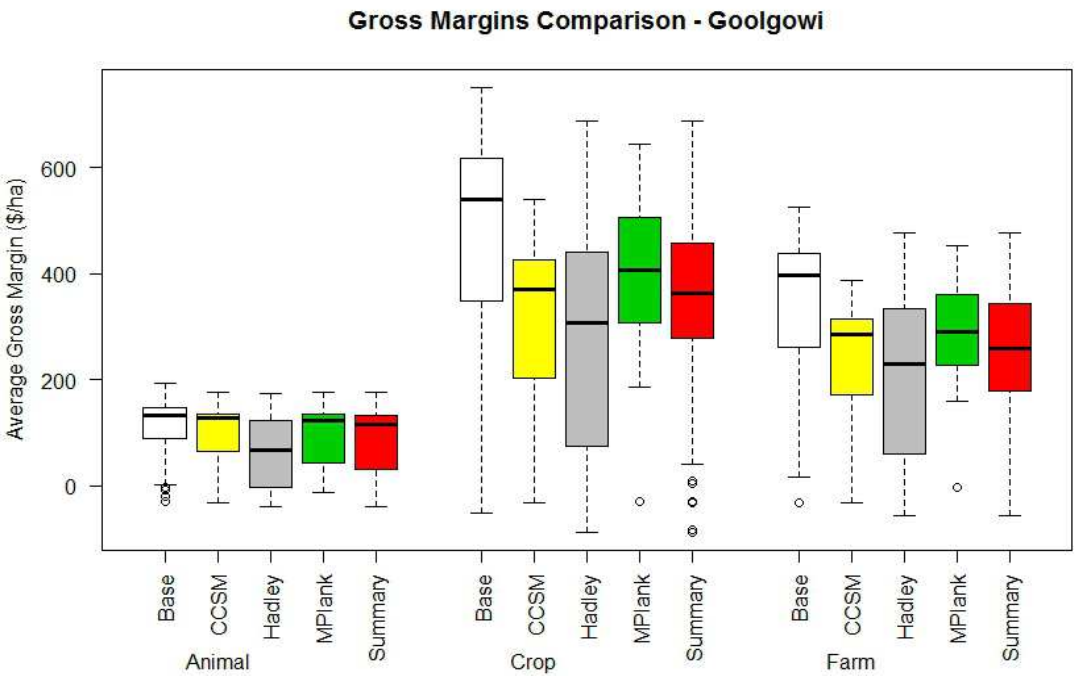

Figure 7. Goolgowi site- gross margin comparison for 2030.

Goolgowi crop production

Figure 8 and Figure 9 show the comparison of historical and projected crop performance under climatic conditions at Goolgowi. Figure 8 presents the finding of crop yield for barley, canola and wheat at Goolgowi. Figure 9 presents the finding of crop harvest date for barley, canola and wheat at Goolgowi. Both graphs show reductions in the expected outcomes under future climate, with the Hadley GCM having the most noticeable negative change in wheat and barley yields and also the largest variability in yields for canola. It is also interesting to note the reduction in the days to harvest across all three GCMs for all crop varieties (Figure 9).

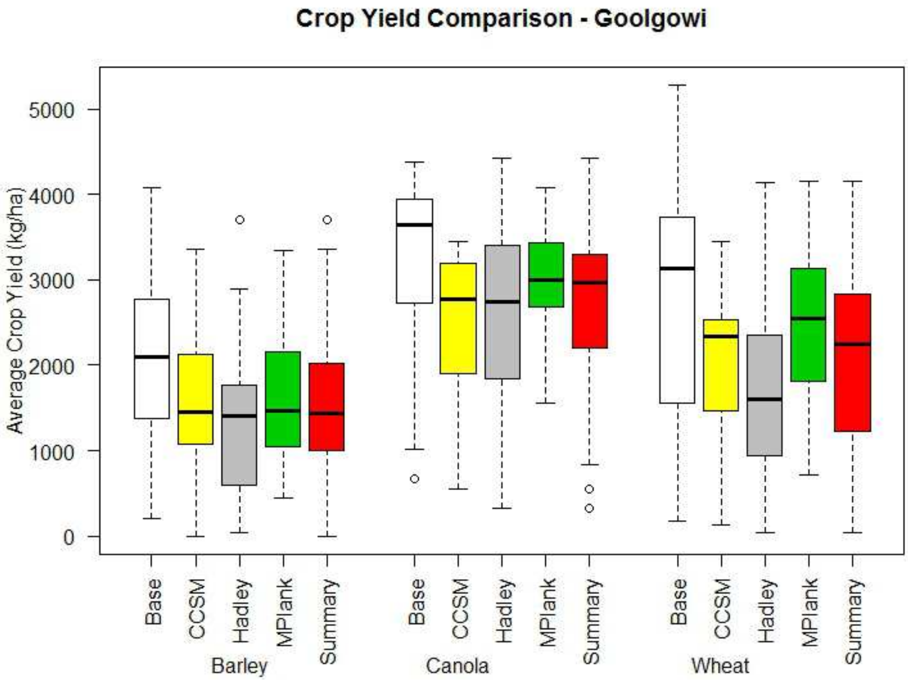

Figure 8. Goolgowi site-crop yield comparison for 2030

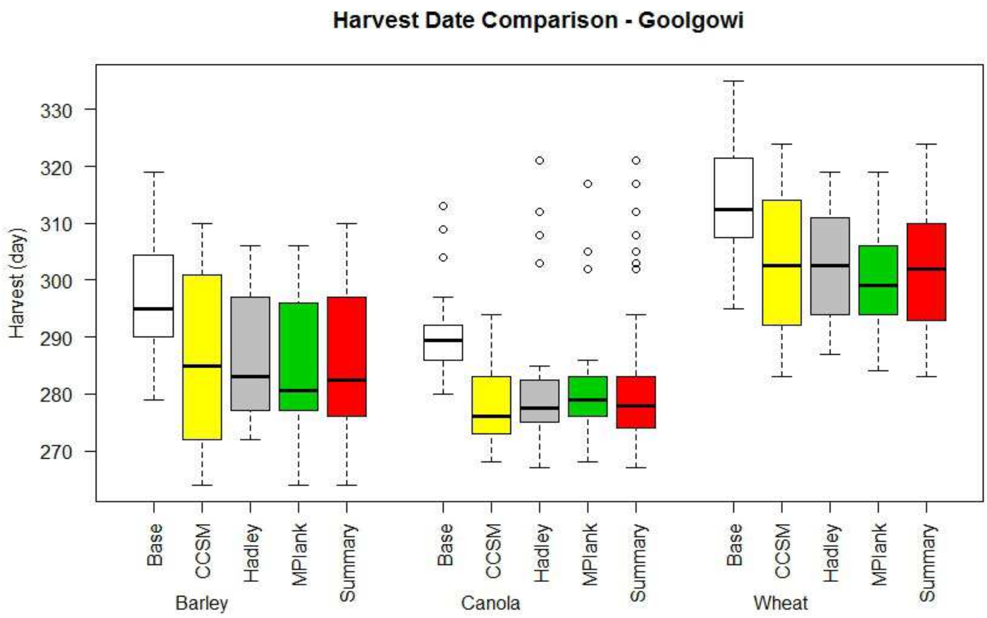

Figure 9. Goolgowi site-harvest day comparison for 2030

Goolgowi pasture production

Figure 10 and Figure 11 show the comparison of historical and projected pasture performance under climatic conditions at Goolgowi. Figure 10 presents the finding of total pasture dry matter at Goolgowi, showing the Hadley GCM is the worst performer and Mon Plank the best and similar to that would be expected under baseline climatic conditions. Figure 11 presents the findings of relative ground cover as a proportion of total pasture cover. Each of the three future climate scenarios show reductions in the minimum amount of ground cover. This will have implications on how pastures are managed and the effect this will have on livestock production under future climate scenarios.

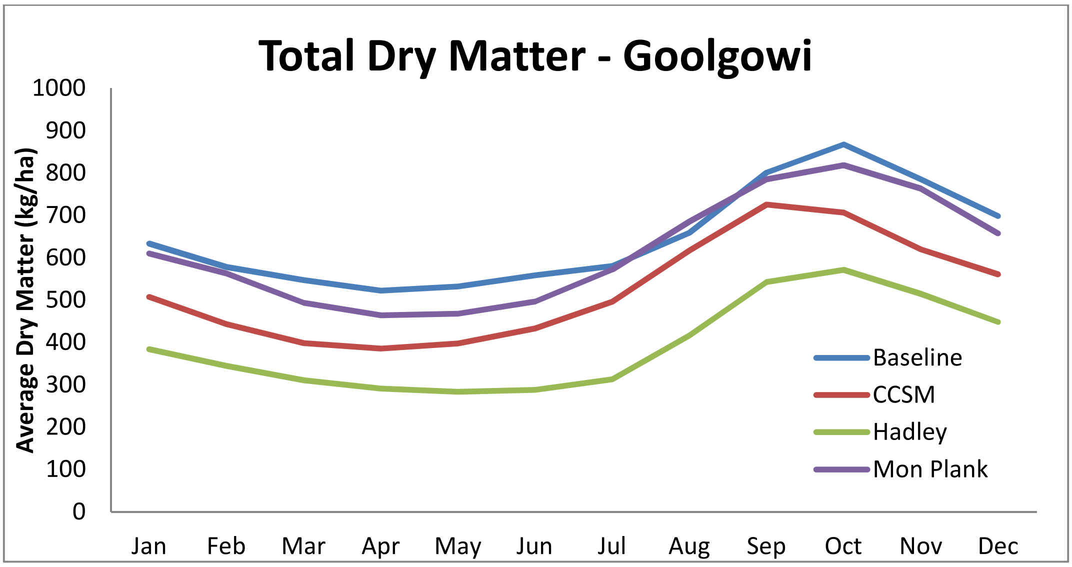

Figure 10. Goolgowi site-total dry matter comparison for 2030

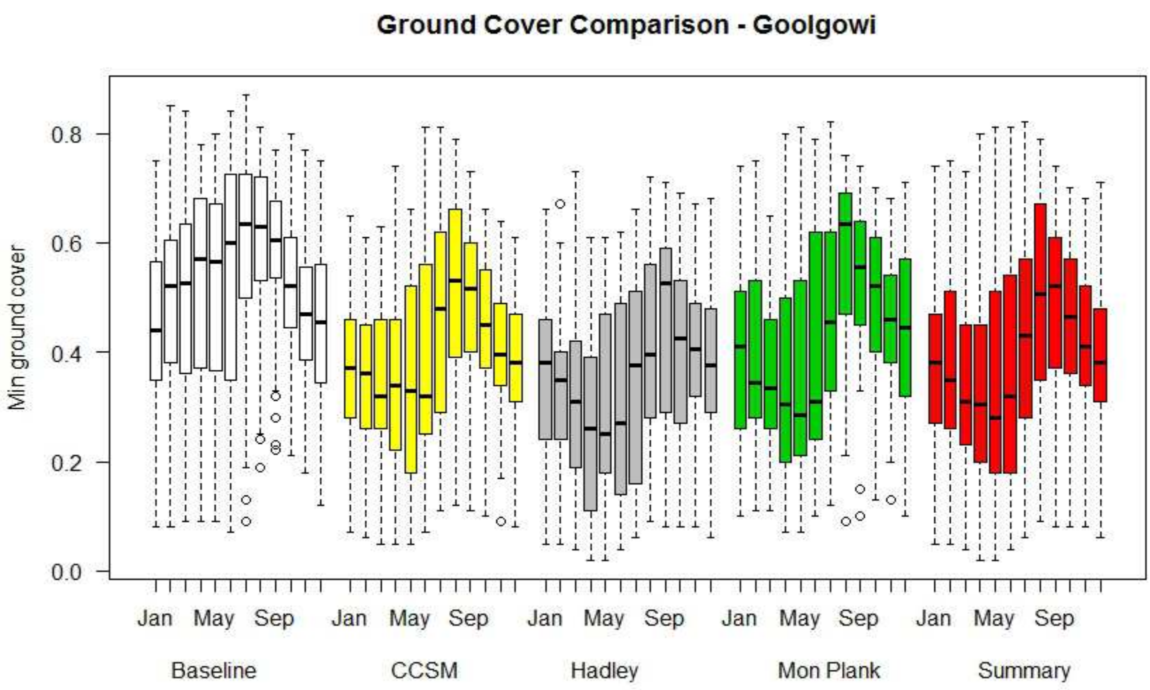

Figure 11. Goolgowi site-ground cover comparison for 2030 as a proportion of cover (0-1)

Goolgowi livestock production

Figure 12, Figure 13 and Table 6 show the comparison of historical and projected animal performance under climatic conditions at Goolgowi. Figure 12 shows a varied response to the amount of annual ewe supplementation required. The Hadley GCM is the most affected with noticeably more supplement being fed. Mon Plank is the best performer, and appears to be similar to the supplement requirements under baseline climatic conditions. This supports the finding in Figure 10, relating to the amount of total dry matter available. Figure 13 presents the findings of average ewe weight at Goolgowi, which again shows Hadley to be the worst performing GCM. Table 6 presents the findings for lamb performance at Goolgowi. When compared to baseline, each of the three GCMs show an expected reduction in the number of lambs in the farming system, drops in lamb weights and animal condition. Across all three variables, Hadley consistently underperforms the other GCMs.

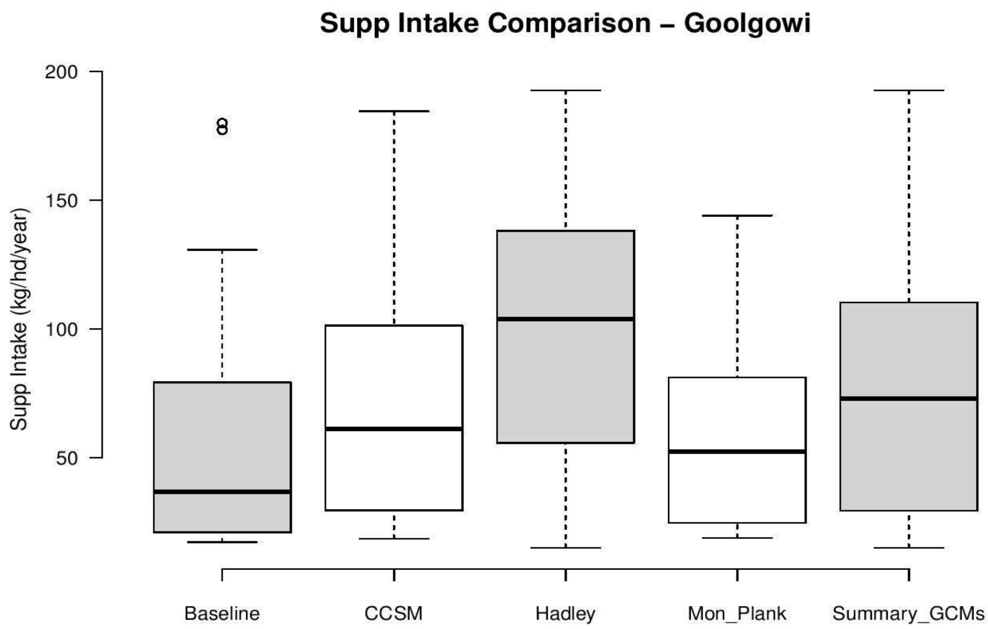

Figure 12. Goolgowi site-supplementary feed intake comparison for 2030

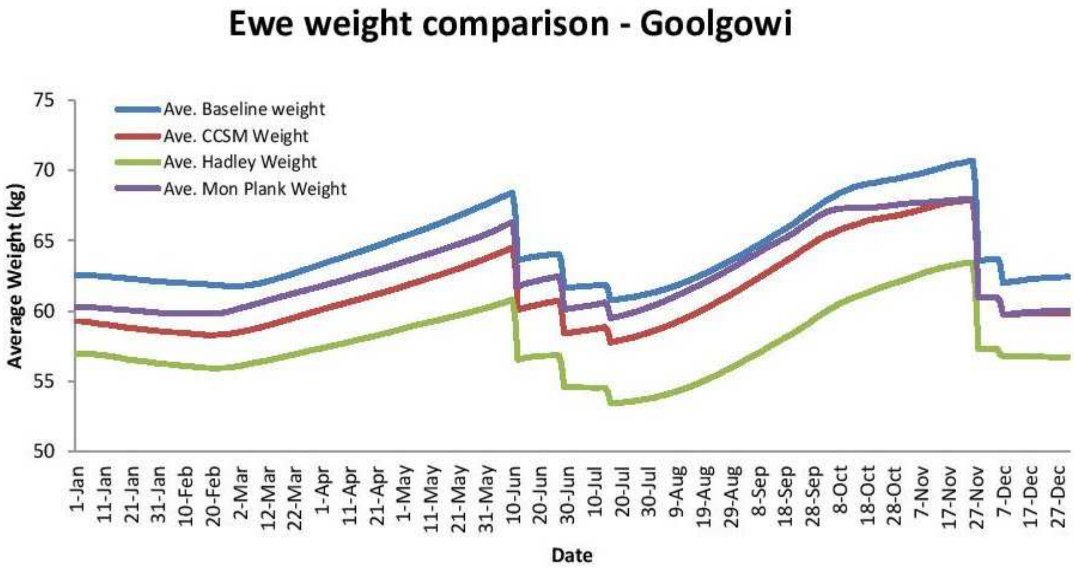

Figure 13. Goolgowi site-ewe weight comparison for 2030

Table 6. Goolgowi site-lamb performance comparison for 2030

Climate Scenario	Ave. Number of lambs	Ave. Max weight (kg)	Ave. Max Condition score
Baseline (No.)	1168	43.43	3.29
CCSM (% change)	-0.4	-4.4	-6.1
Hadley (% change)	-3.7	-12.8	-11.6
Mon Plank (% change)	-0.3	-1.4	-1.2
Average 3 GCMs (% change)	-1.5	-6.2	-6.3

Adaptation assessment – Goolgowi

Goolgowi sowing adaptation

Figure 14 and Figure 15 present the economic response to implementation of the ‘sowing’ rule at Goolgowi under the 3 future climate scenarios. Figure 14 illustrates the effect of implementing the ‘sowing’ rule on total farm gross margins and Figure 15 illustrates the effect of the ‘sowing’ rule on crop gross margins. Both figures show the variations of future climate scenarios (CCSM, Hadley & Mon Plank) compared to historic conditions (baseline). Implementing the sowing rule has reduced the variability for both CCSM and Hadley GCMs (when compared to the CCSM/Hadley baseline) and also reduced the probability of lower end returns. There is little difference when comparing the Mon Plank baseline with the sowing adaptation. This trend is also seen in Figure 15.

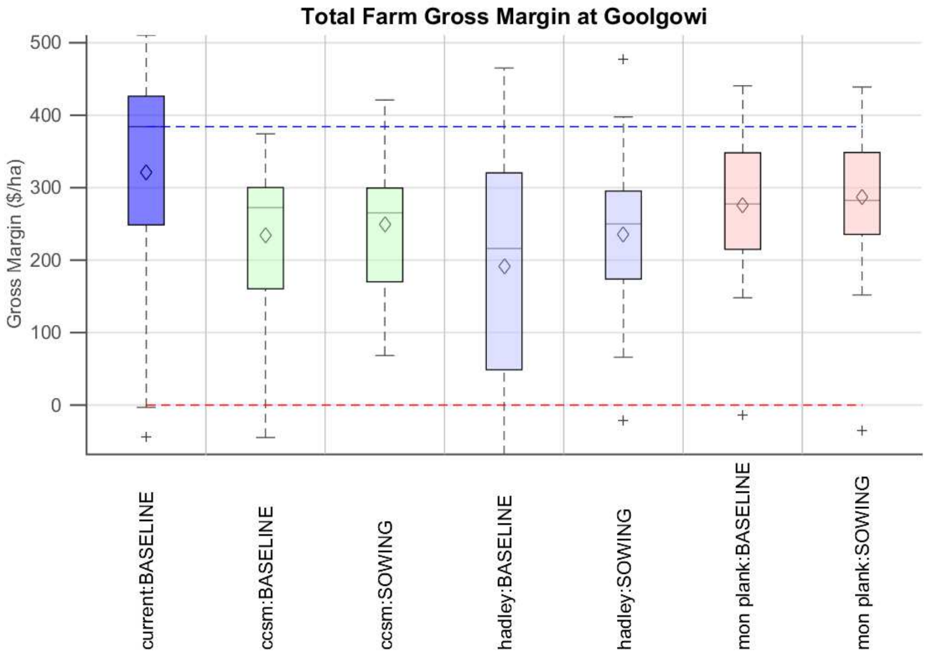

Figure 14. Total farm gross margin ($/ha) highlighting the effect of implementing the sowing adaptation under different climate scenarios. ‘BASELINE’ is current management and ‘SOWING’ is adaptation. Dashed blue line is median gross margins under current management. Dashed red line is the breakeven point. Diamonds represent average value.

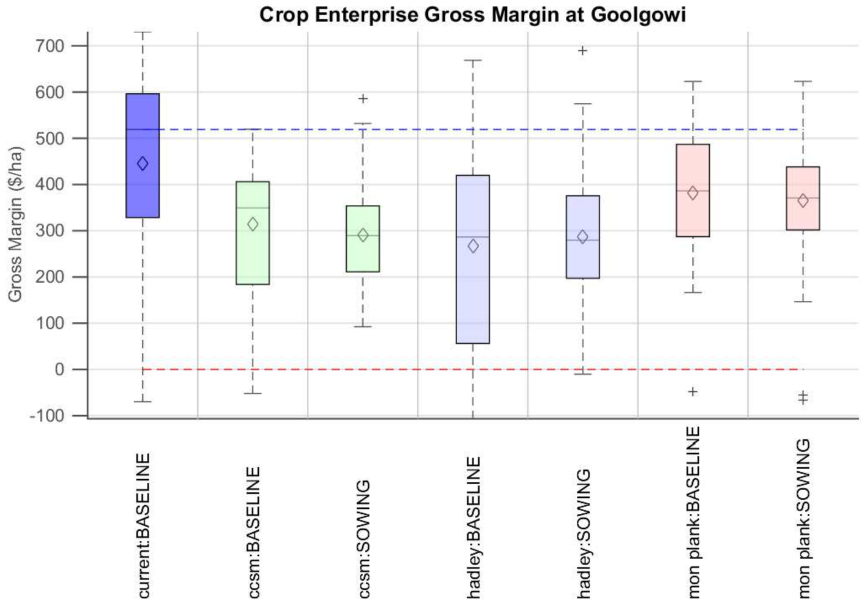

Figure 15. Crop gross margin ($/cropped ha) highlighting the effect of implementing the sowing adaptation under different climate scenarios.

Figure 16 illustrates the effect on crop yield of implementing the 'sowing' rule on each of the 3 crop types represented at Goolgowi. When examining individual crops, there is a noticeable positive improvement on yields under the sowing adaptation for both Hadley and Mon Plank, and little change when applying the sowing adaptation to the CCSM GCM.

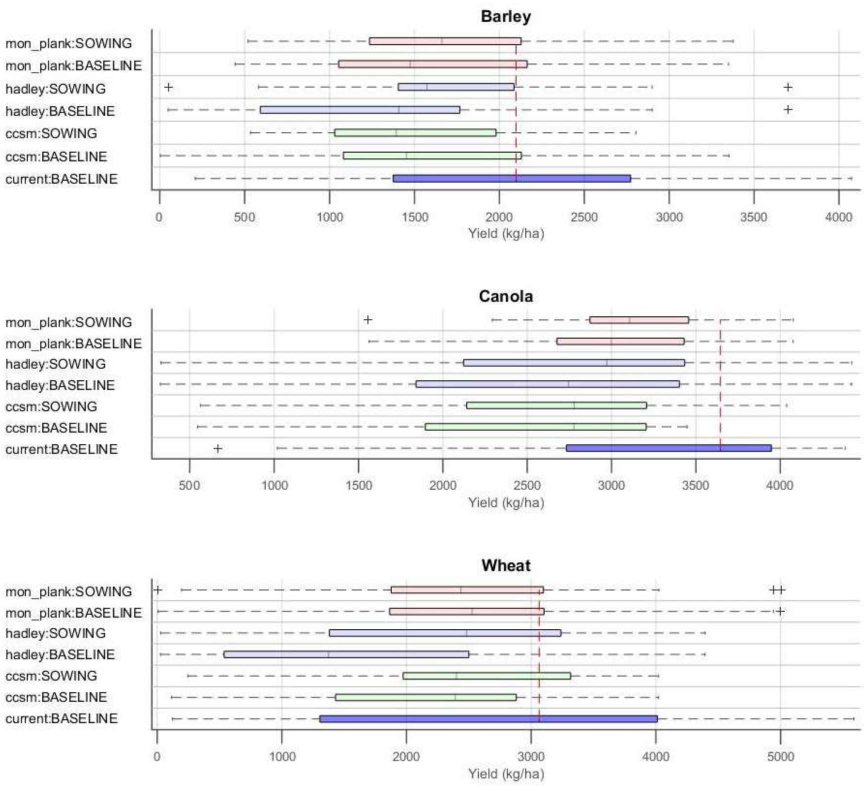

Figure 16.Crop yields (kg/ha) highlighting the effect of implementing the sowing adaptation under different climate scenarios.

Table 7 provides a summary of the number of years when the 'sowing' adaptation was triggered under the future climate scenario. CCSM and Hadley were the most affected by the sowing adaptation, which would directly relate to the climatic conditions experienced under these two climate scenarios. It is also important to consider the number of years that the final crop in the rotation (barley) was not sown. This has implications for the pasture phase of the farming system as pasture is undersown with the barley, resulting in no pasture being sown and therefore reducing the access livestock have to pasture paddocks for the following three years.

Table 7. The number of years that the sowing adaptation was enacted.

Effect of Sowing Adaptation	CCSM	Hadley	Mon Plank
Number of years last rotation (barley) was not sown*	6 (23%)	5 (19%)	2 (8%)
Number of years that no wheat was sown (in any paddock)	3 (15%)	5 (19%)	1 (4%)
Number of years no crops were sown	1 (4%)	1 (4%)	1 (4%)
Number of years only one crop was sown (canola only)	3 (12%)	4 (15%)	0

* reducing the number of paddocks in pasture for the next three years (placed into a fallow instead)

Goolgowi genetics adaptation

Figure 17 and Figure 18 present the economic response to implementation of the 'genetics' adaptation at Goolgowi under the 3 future climate scenarios. Figure 17 illustrates the effect of implementing the 'genetics' adaptation on total farm gross margins. There appears to be a slight effect on the gross margins across the three individual GCMs due to the genetics adaptation. However when examining the gross margins for the livestock component (Figure 18), all three GCMs did respond to the genetics adaptation. Most noticeably was the CCSM GCM with a large decrease in the probability of lower end returns.

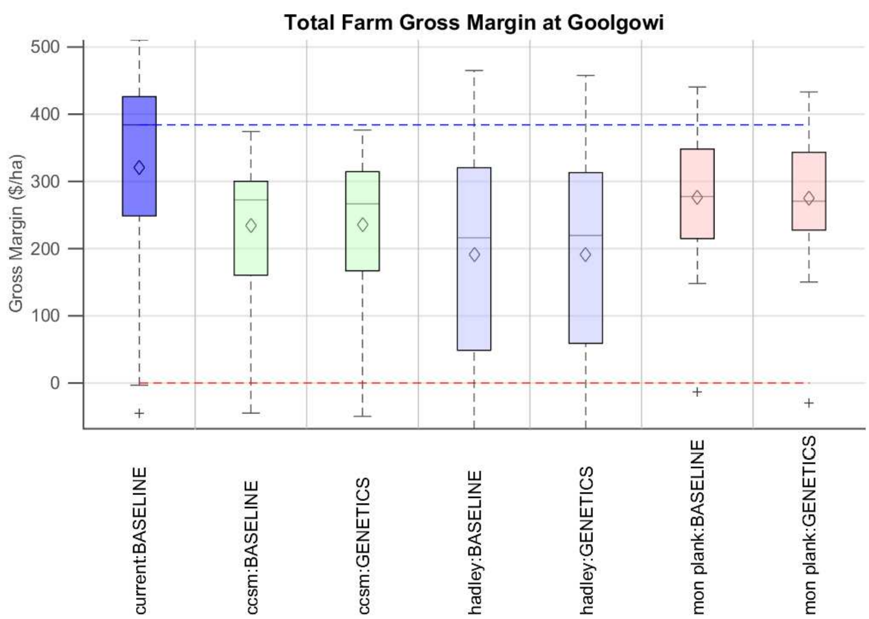

Figure 17. Total farm gross margin ($/ha) highlighting the effect of implementing the genetics adaptation under different climate scenarios.

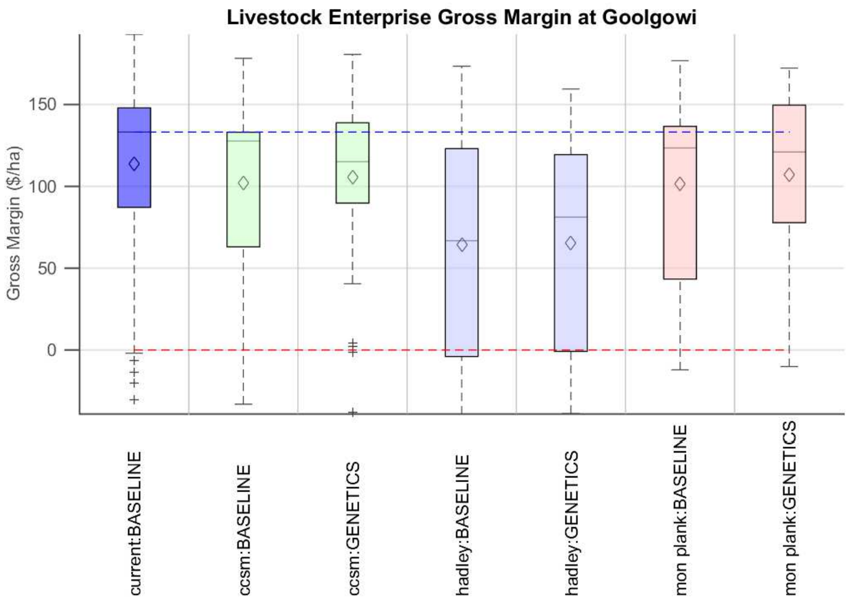

Figure 18. Livestock enterprise gross margin ($/grazed ha) highlighting the effect of implementing the genetics adaptation under different climate scenarios.

Figure 19 and Table 8 illustrate the change in lamb performance from implementation of the 'genetics' adaptation at Goolgowi. Figure 19 displays the response in lamb weight to implementation of the 'genetics' adaptation. All three GCMs showed a noticeable positive response to the genetics adaptation, with Mon Plank even outperforming the current baseline results when the genetics adaptation was implemented. Table 8 displays the comparison in the number of days from lamb weaning to sale from implementation of the 'genetics' adaptation. All three GCMs were found to respond positively to the genetics adaptation, with lambs reaching sale criteria quicker than their corresponding GCM baseline. It should be noted that this analysis did not allow for altered selling dates with all animals sold within a static window, potentially higher growth rates could offer opportunities to turn stock off earlier.

Table 8. Number of days from lamb weaning to sale date.

Climate	Adaptation	Female Lambs	Male Lambs
		Median Days to sale	Median Days to sale
Current	Baseline	54	44
CCSM	Baseline	60	50
CCSM	Genetics	54	44
Hadley	Baseline	67	54
Hadley	Genetics	59	50
Mon Plank	Baseline	56	48
Mon Plank	Genetics	51	43

* 42 days is the first available sale opportunity, 114 days is the last available sale opportunity

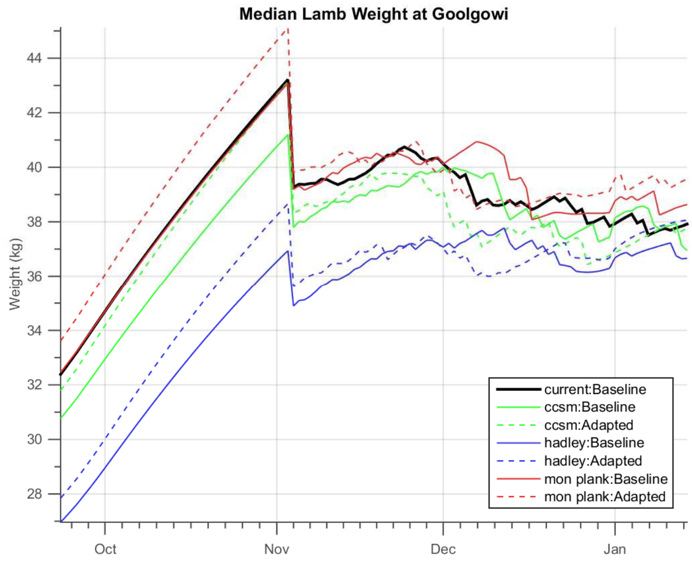

Figure 19. Median lamb weight (kg/animal) highlighting the effect of implementing the genetics adaptation under different climate scenarios.

Goolgowi cover adaptation

Figure 20, Figure 21 and Figure 22 illustrate the response to the implementation of the 'cover' adaptation. Figure 20 illustrates the effect of implementing the adaptation on total farm gross margins. There was found to be little effect from applying the cover adaptation for all three GCMs. Figure 21 displays the effect of implementing the 'cover' adaptation on long term average pasture cover, again showing little change with implementing the cover adaptation. Figure 22 displays the effect of implementing the 'cover' adaptation on ewe supplementation. There does appear to be a slight decrease in the amount of supplementary feed required, particularly for the Mon Plank and CCSM climate scenarios during autumn. It is also interesting to note the difference in the distribution of supplement intake between the three future climate scenarios.

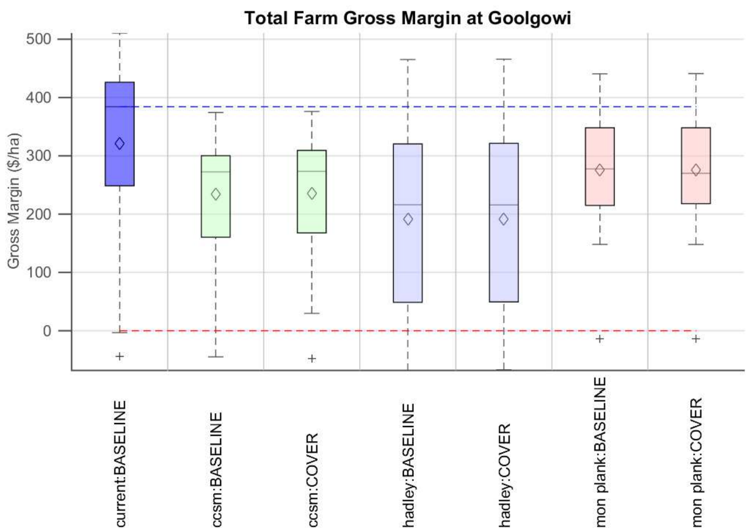

Figure 20. Total farm gross margin ($/ha) highlighting the effect of implementing the cover adaptation under different climate scenarios.

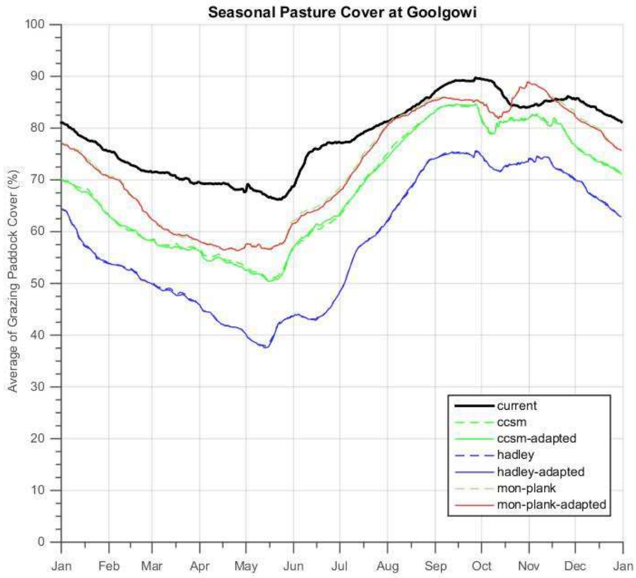

Figure 21. Long term average (%) pasture cover (aggregated to the whole farm as median across all paddocks) highlighting the effect of implementing the cover adaptation under different climate scenarios.

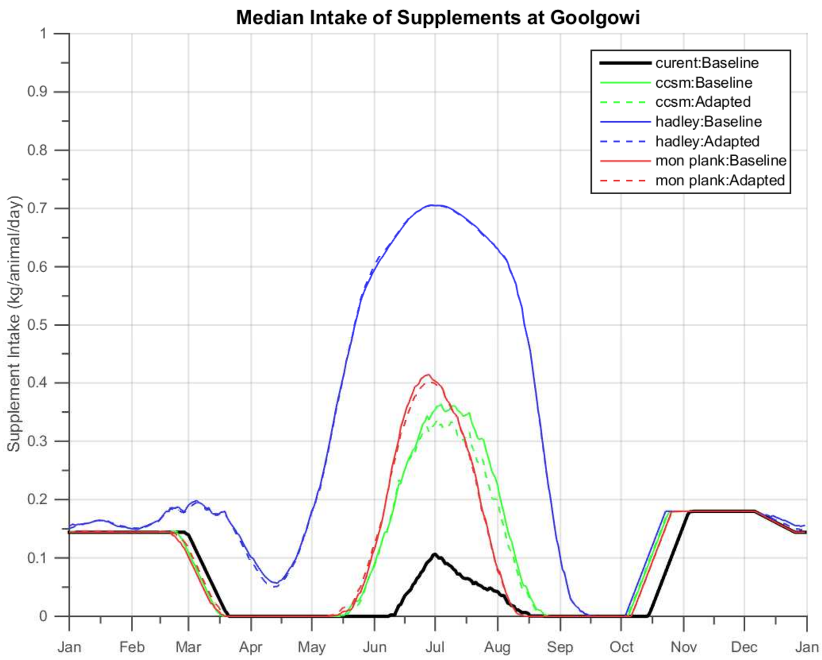

Figure 22. Long term median supplement fed to ewes (kg/head/day) highlighting the effect of implementing the cover adaptation under different climate scenarios.

Summary - Goolgowi

The average impact for the project change for Goolgowi includes;

- slight to moderate decrease of economic return,
- a slight decrease in crop yield at least in part driven by a shortening of the growing season (exception being Barley),
- decrease in annual pasture dry matter production and slight change in seasonality ,
- moderate increase in the amount of animal supplementation required to meet livestock requirements,
- decrease in ewe body weight and condition score, and
- a decrease number of weaned lambs and lower average condition.

At the Goolgowi site implementation of the adaptation option showed;

- the 'sow' rule improved gross margins at both the farm and crop level and decreased the probability of lower end returns. This was driven by increases in average yield and tightening yield probabilities.
- the 'genetics' rule improved gross margins at both the farm and animal level and increased probabilities of higher end returns. This result was driven by faster finishing times from increases in lamb weight gain.
- The 'cover' rule had no notable impact on farm gross margins, seasonal pasture cover or level of supplementation required.

A detailed summary of the response of each GCM run to the 3 adaptation option can be found in Appendix 7.

Impact assessment - Temora

Temora climate

Figure 23, Figure 24 and Figure 25 show the comparison of historical and projected climatic conditions at Temora. Figure 22 shows the range of potential rainfall compared to historical measurements. Figure 23 shows that there is an overall expected increase in both average maximum and minimum daily temperatures throughout the year, with increase of up to 2°C. The occurrence and projected changes in winter/spring frost (Figure 25) shows a slightly higher probability of later season frosts. This increased incidence of later frosts has the potential of effecting crop performance. A more detailed monthly statistical analysis including an assessment of rainfall and maximum temperatures can be found in Appendix 6.

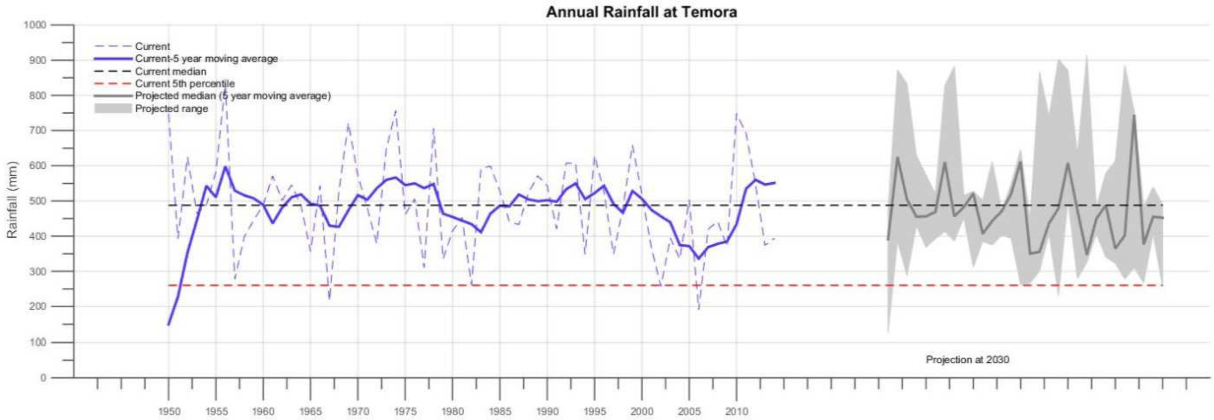

Figure 23. Long term variability in annual rainfall at Temora with the range of climate model projections at 2030.

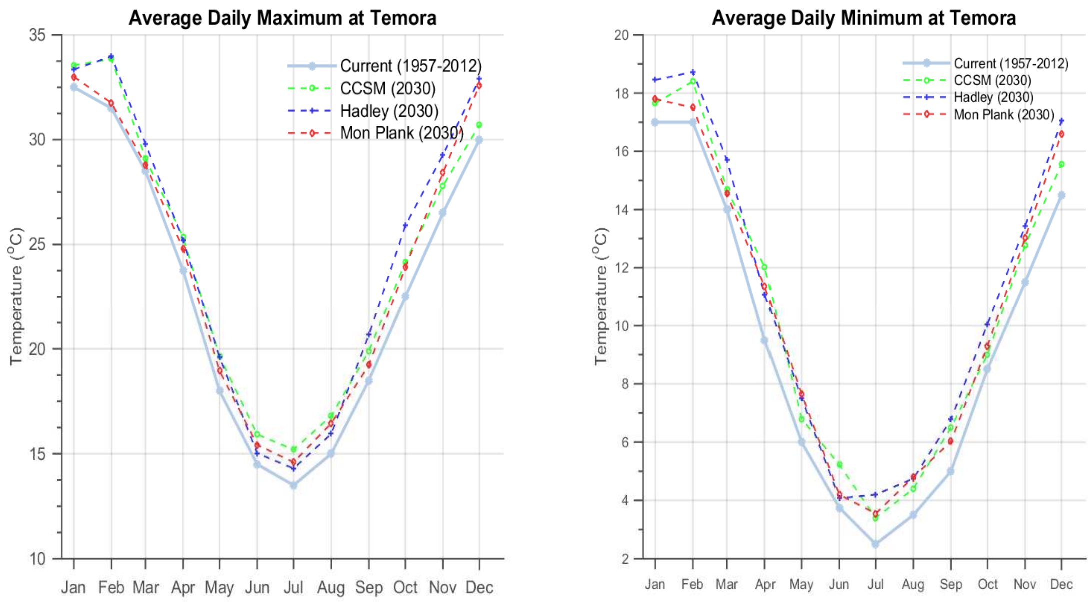

Figure 24.The maxima and minima monthly temperatures at Temora for current climate and the projected period (2030).

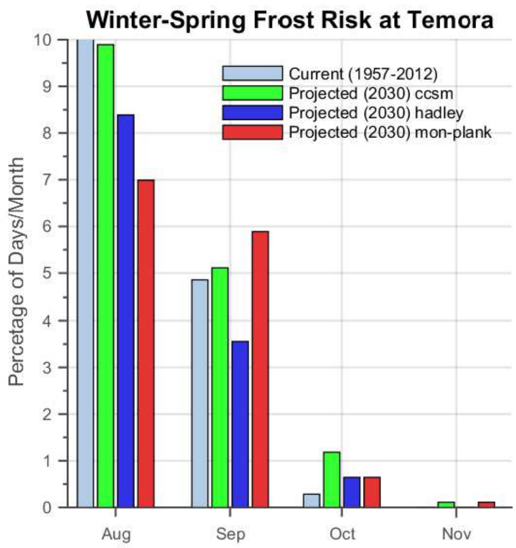

Figure 25.Late winter/spring frost risk at Temora, where a frost is a minimum daily temperature below 0 degrees C.

Temora economics

Figure 26 presents the gross margin calculations for Temora for the animal, crop and whole farm component of the farming enterprise, comparing historic conditions to future climate scenarios (CCSM, Hadley, Mon Plank). The data shows that there is large variability between each of the three GCMs, with the Mon Plank climate scenario most similar to the baseline period. When examining the summary boxplot, it suggests that there will be decreases in expected gross margins for the animal and whole farm components of the farming system and a slight change in the cropping component.

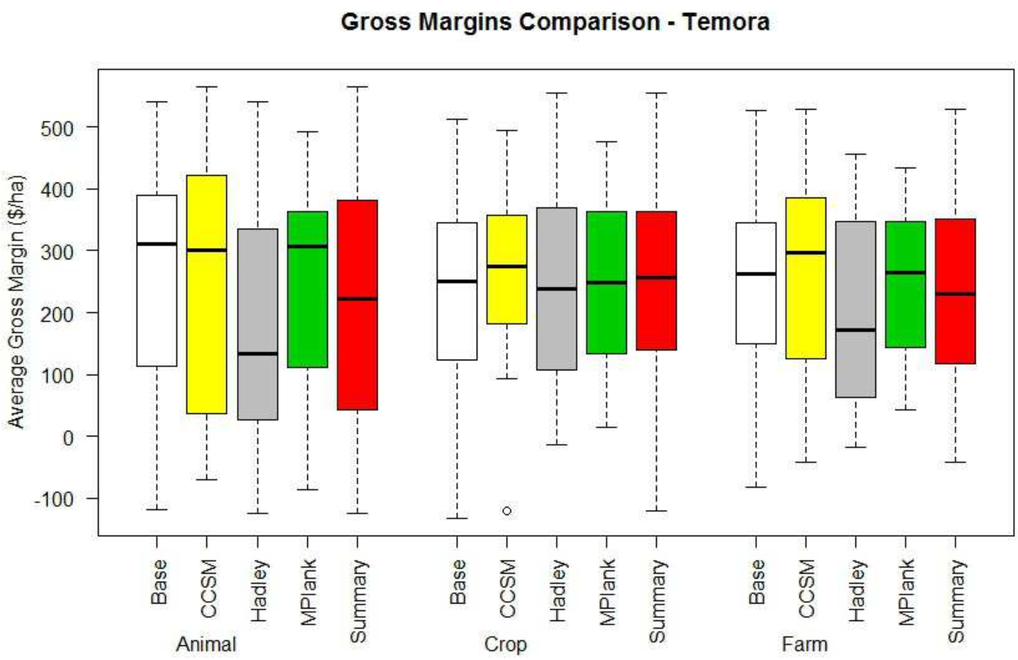

Figure 26. Temora site- gross margin comparison for 2030.

Temora crop production

Figure 27 and Figure 28 show the comparison of historical and projected crop performance under climatic conditions at Temora. Figure 27 presents the findings of crop yield for barley, canola and wheat at Temora. While there tends to be no obvious patterns in the average crop yield median value (horizontal line), there is a tightening up of the yields (reduction in the high variability that could be expected). Figure 28 presents the finding of crop harvest date for barley, canola and wheat at Temora. There has been a reduction in the days to harvest across all three CGMs for each of the three crop types.

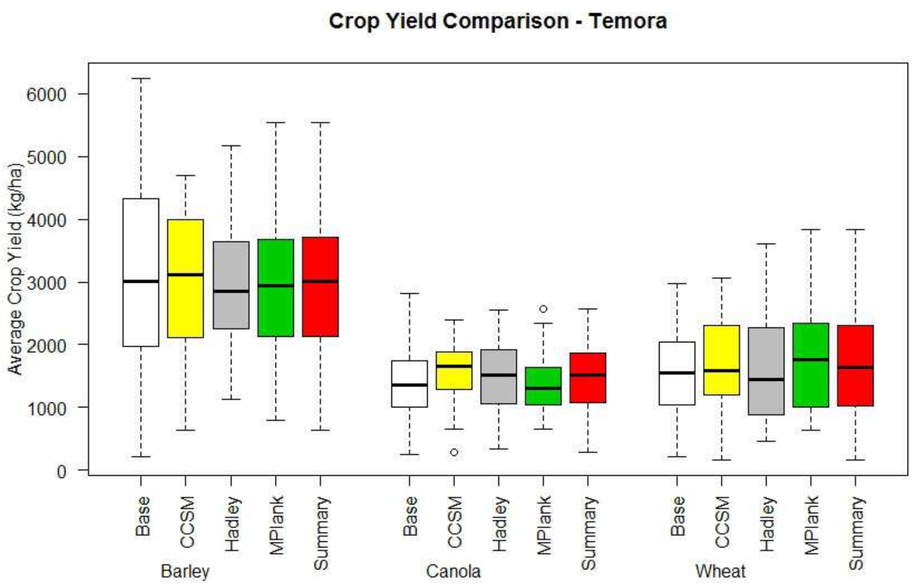

Figure 27. Temora site-crop yield comparison for 2030.

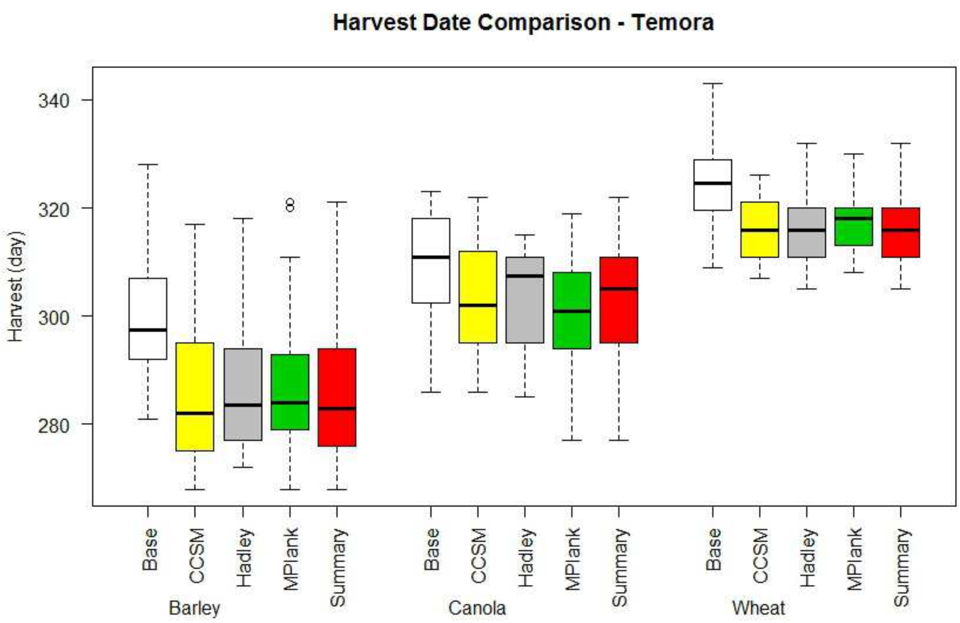

Figure 28. Temora site-harvest day comparison for 2030.

Temora pasture production

Figure 29 and Figure 30 show the comparison of historical and projected pasture performance under climatic conditions at Temora. Figure 29 presents the finding of total pasture dry matter at Temora, showing the Hadley GCM as the worst performer and CCSM and Mon Plank at similar (though slightly reduced) levels that would be expected under baseline climatic conditions. Figure 30 presents the findings of relative ground cover as a proportion of total pasture cover at Temora. Each of the 3 future climate scenarios show reductions in the minimum amount of ground cover, with the Hadley GCM showing the biggest decreases.

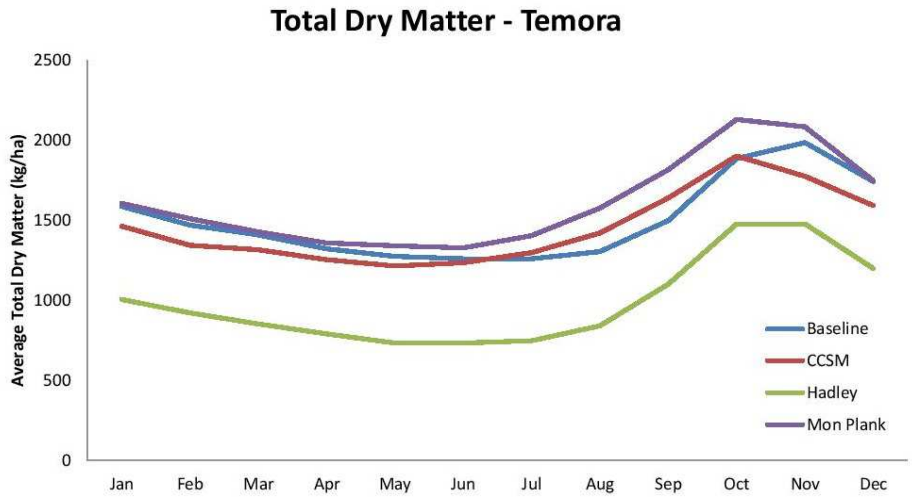

Figure 29. Temora site-total dry matter comparison for 2030

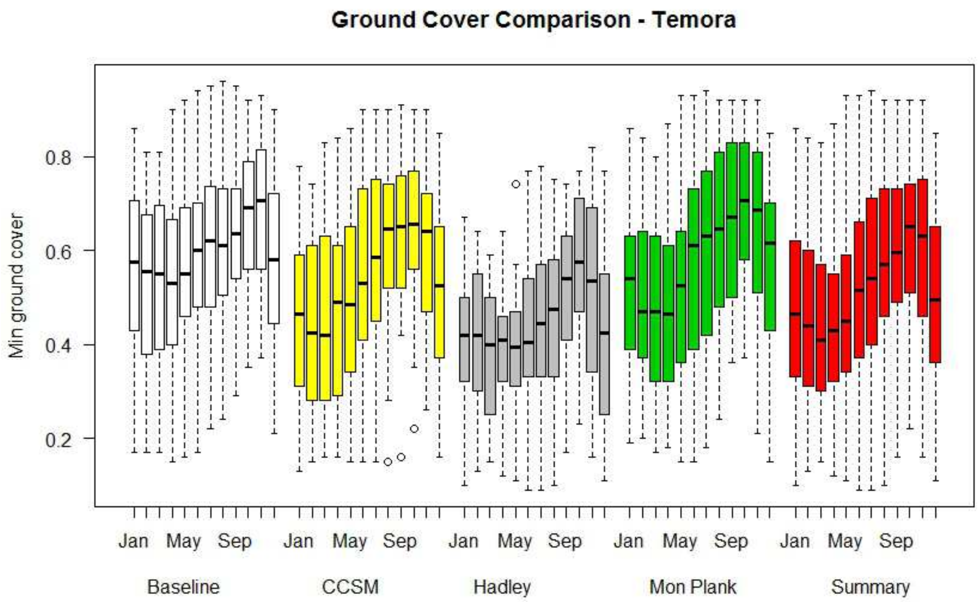

Figure 30. Temora site-ground cover comparison for 2030 as a proportion of cover (0-1)

Temora livestock production

Figure 31, Figure 32 and Table 9 show the comparison of historical and projected animal performance under climatic conditions at Temora. Figure 31 shows a varied response to the amount of annual ewe supplement required. The Hadley CGM is more noticeably affected with more supplement being fed. Mon Plank is the most similar to baseline conditions. This supports the findings in Figure 29, relating to the amount of total dry matter available. Figure 32 presents the findings of average ewe weight at Temora, which again highlights the negative impact of the Hadley CGM on performance. Table 9 presents the findings of average lamb performance at Temora. When compared to the baseline, there are only minor differences for each of the three GCMs in the number of lambs in the system and lamb weights. However the Hadley GCM has a much larger reduction in the lambs' condition (13% reduction) compared to the other future climate scenarios.

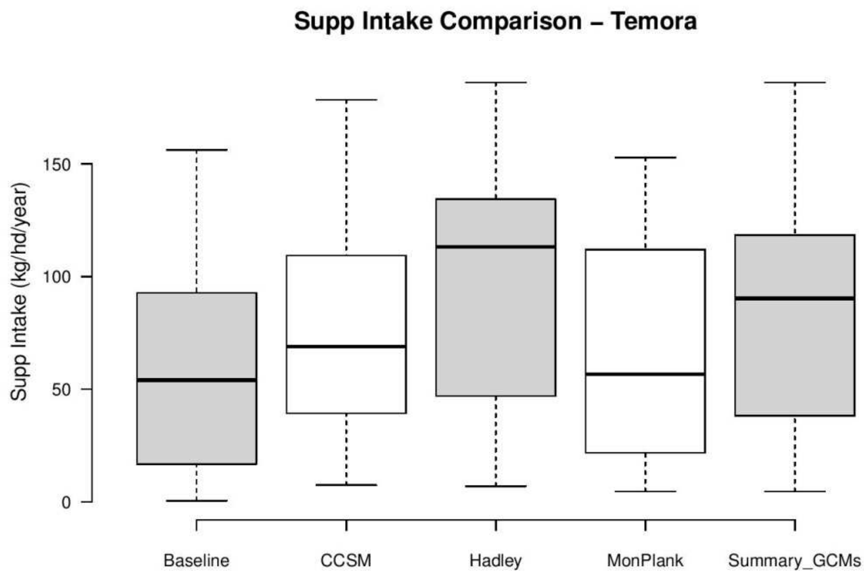

Figure 31. Temora site-supplementary feed intake comparison for 2030

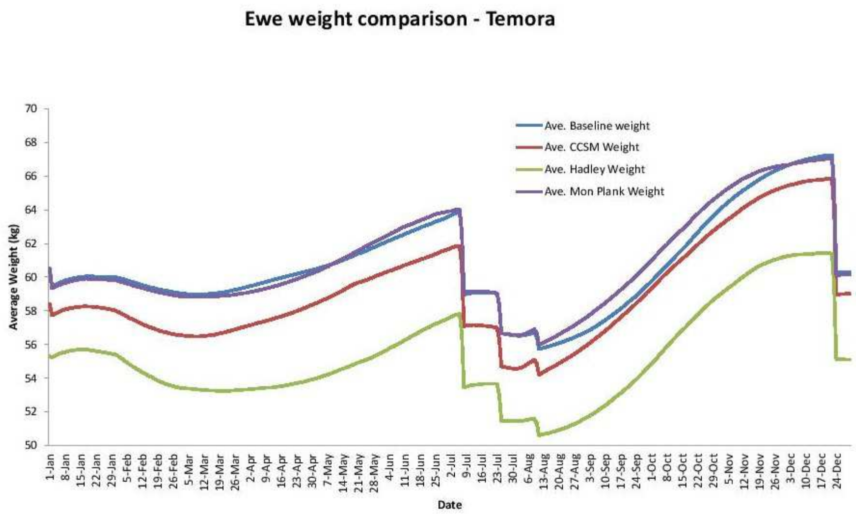

Figure 32. Temora site-ewe weight comparison for 2030.

Table 9. Temora site-lamb performance comparison for 2030.

Climate Scenario	Ave. Number of lambs	Ave. Max weight (kg)	Ave. Max Condition score
Baseline (No.)	2854	39.9	3.0
CCSM (% change)	1	-2	-3
Hadley (% change)	-1	-3	-13
Mon Plank (% change)	1	1	0
Average 3 GCMs (% change)	1	-1	-5

Adaptation assessment - Temora

Temora sowing adaptation

Figure 33 and

Figure 34 presents the economic response to implementation of the 'sowing' rule at Temora under the 3 future climate scenarios. Figure 33 illustrates the effect of implementing the 'sowing' rule on total farm gross margins and

Figure 34 illustrates the effect of the implementing the 'sowing' rule on crop gross margins. Both figures show the variations of future climate scenarios (CCSM, Hadley & Mon Plank) compared to historic conditions (baseline). Implementing the sowing adaptation has decreased the average gross margins across both the farm (Figure 33) and for individual crops (Figure 34). When examining crop gross margins more closely (Figure 34), across all 3 GCMs there is a broadening of return probabilities.

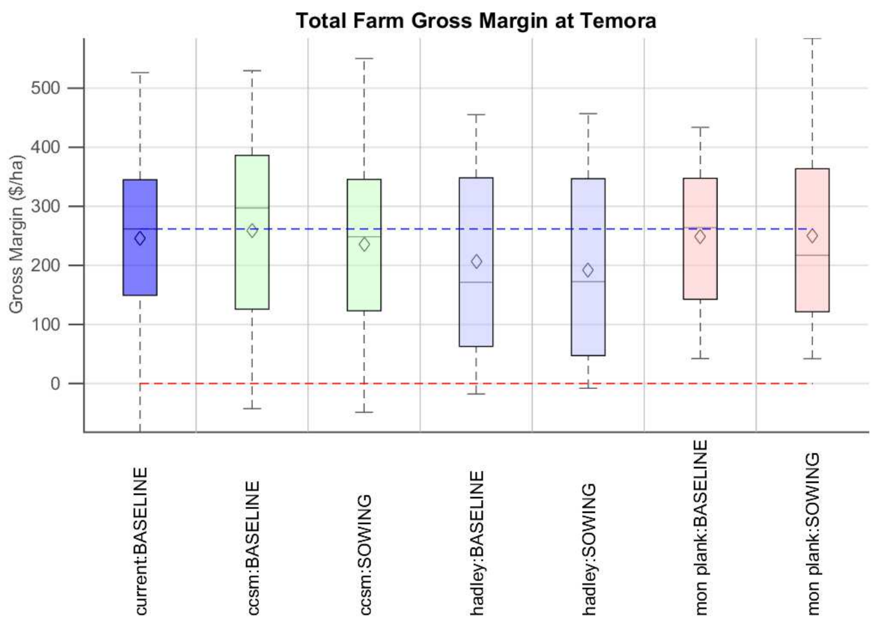

Figure 33. Total farm gross margin ($/ha) highlighting the effect of implementing the sowing adaptation under different climate scenarios.

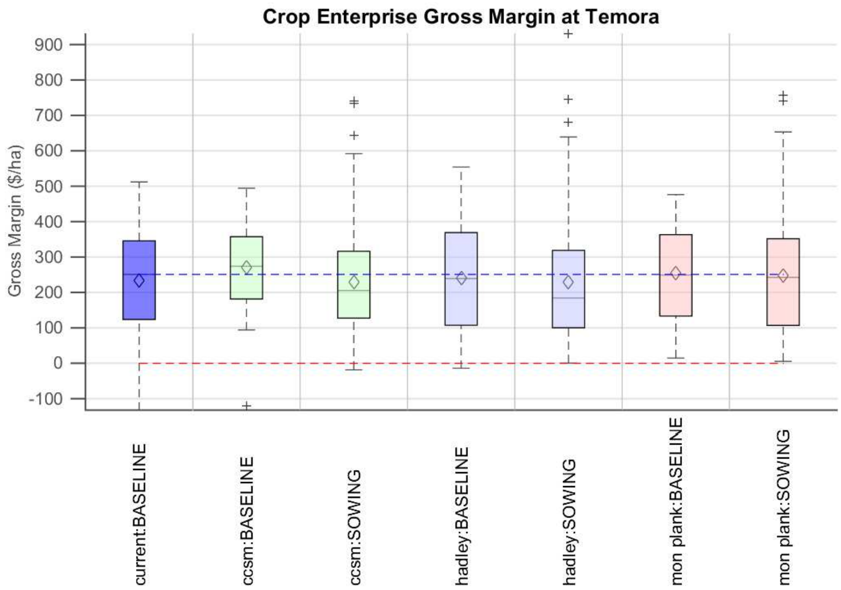

Figure 34. Crop gross margin ($/cropped ha) highlighting the effect of implementing the sowing adaptation under different climate scenarios.

Figure 35 illustrates the effect on crop yield of implementing the 'sowing' rule on each of the 3 crop types represented at the Temora site. When examining individual crops, there is a noticeable improvement under the sowing adaptation for wheat for all three GCMs, though only Mon Plank and Hadley showed a positive response for Barley, while Canola reacted positively under the Mon Plank and CCSM climate scenarios.

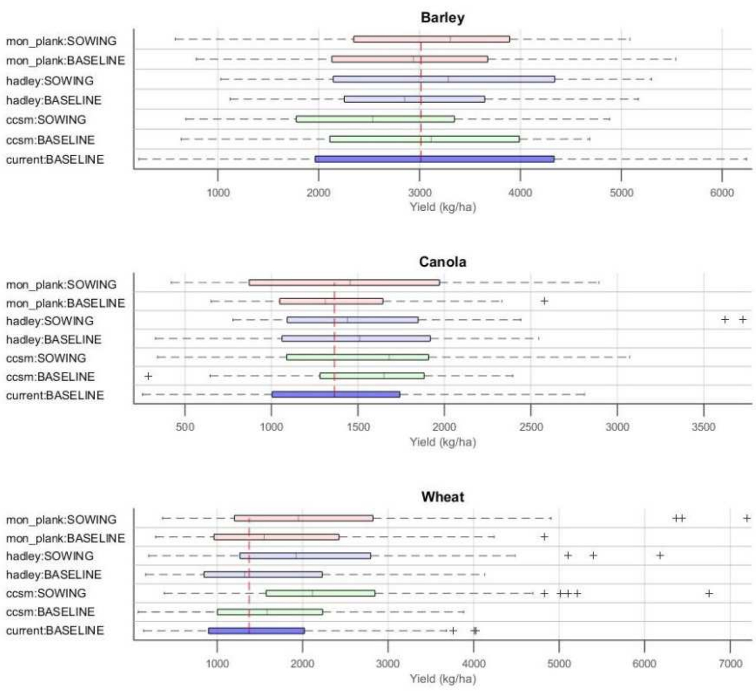

Figure 35. Crop yields (kg/ha) highlighting the effect of implementing the sowing adaptation under different climate scenarios.

Table 10 provides a summary of the number of years when the 'sowing' adaptation was triggered under the future climate scenario. Although the modelling results show that there was never an occurrence that no crops were sown due to the sowing adaptation, they were several years that only one or two paddocks were sown, which would in turn influence crop and farm gross margins. It is also interesting to note that all three GCMs experienced a high percentage of years where the final crop (wheat) in the rotation was not sown due to the sowing adaptation. Not only does this influence yields and gross margins, it also implications for the pasture phase of the farming system as pasture is undersown with the final wheat crop, resulting in no pasture being sown and therefore reducing the access livestock have to pasture paddocks for the following three years.

Table 10. The number of years that the sowing adaptation was enacted.

Effect of Sowing Adaptation	CCSM	Hadley	Mon Plank
Number of years last rotation (wheat) was not sown*	8 (31%)	6 (23%)	5 (19%)
Number of years canola was not sown	7 (27%)	10 (38%)	5 (19%)
Number of years first crop (wheat) in rotation was not sown[@]	3 (12%)	6 (23%)	4 (15%)
Number of years no crops were sown	0	0	0
Number of years only one crop was sown	3 (12%)	4 (15%)	1 (4%)
Number of years only two crops were sown	0	1 (4%)	2 (8%)

* reducing the number of paddocks in pasture for the next five years (placed into a fallow instead) [@] extending the pasture phase of the rotation for an additional year

Temora genetics adaptation

Figure 36 and Figure 37 present the economic response to implementation of the 'genetics' adaptation at Temora under the 3 future climate scenarios. Figure 36 illustrates the effect of implementing the 'genetics' adaptation on total farm gross margins. There appears to be a varying effect on gross margins across the three GCMs. Under the genetics adaptation, both CCSM and Mon Plank climate scenarios have responded positively, obtaining better average gross margins and also increasing the probability of receiving higher end returns, which is also reflected in Figure 37 (livestock gross margins). Although the average gross margin for Hadley has slightly improved, there has also been an increase probability of lower end returns.

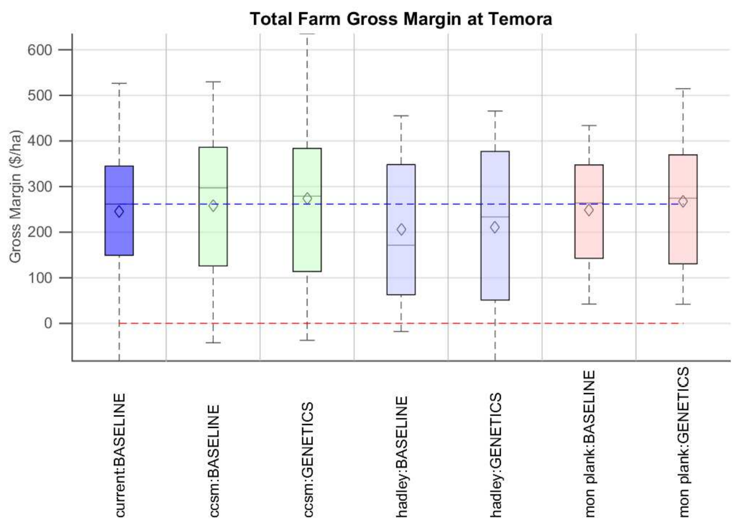

Figure 36. Total farm gross margin ($/ha) highlighting the effect of implementing the genetics adaptation under different climate scenarios.

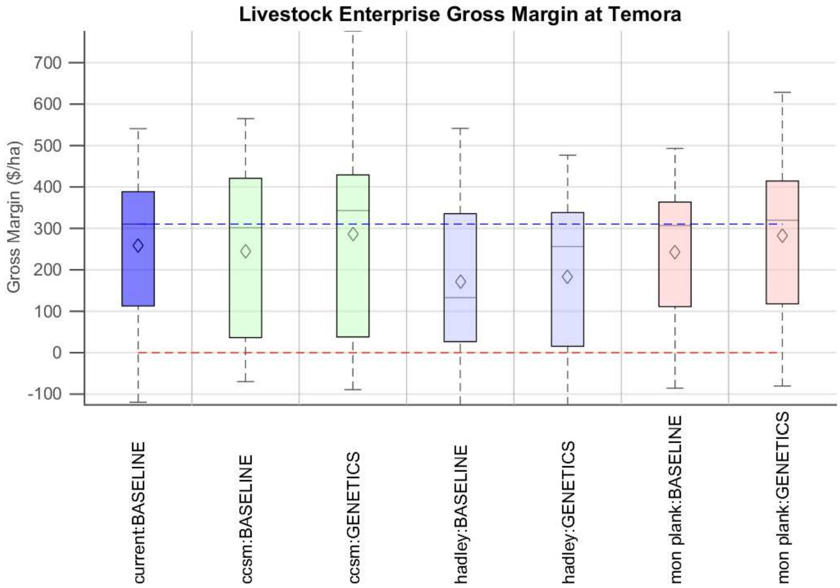

Figure 37. Livestock enterprise gross margin ($/grazed ha) highlighting the effect of implementing the genetics adaptation under different climate scenarios.

Figure 38 and Table 11 present the change in lamb performance from implementation of the 'genetics' adaptation at Temora. Figure 38 displays the response in lamb weight to implementation of the 'genetics' adaptation. All three GCMs showed noticeable positive response to the genetics adaptation, with both Mon Plank and CCSM outperforming the current baseline results when the genetics adaptation was implemented. Table 11 displays the comparison in the number of days from lamb weaning to sale from implementation of the 'genetics' adaptation. All three GCMs were found to respond positively to the genetics adaptation, with lambs reaching sale criteria quicker than their baseline. Reaching critical sale weight more quickly provides an opportunity to turn lambs off more quickly and reduces the pressure on ground cover.

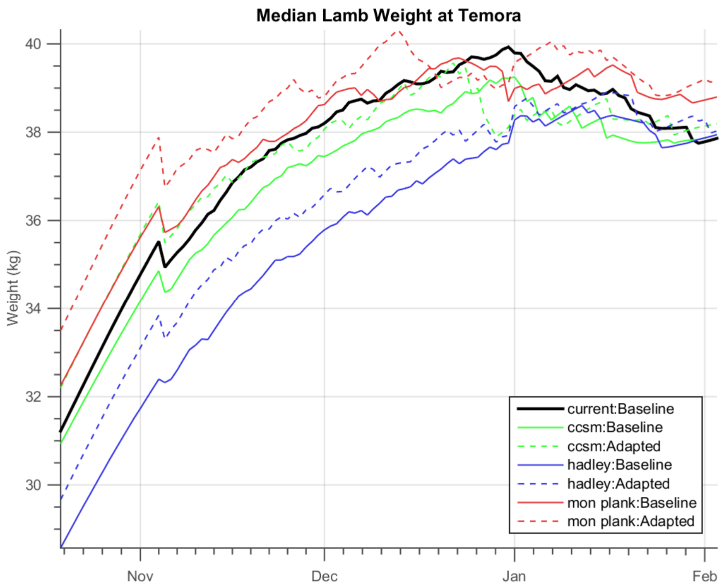

Figure 38. Median lamb weight (kg/animal) highlighting the effect of implementing the genetics adaptation under different climate scenarios. 'BASELINE' is current management and 'ADAPTED' is genetics adaptation.

Table 11. Number of days from lamb weaning to sale date.

Climate	Adaptation	Female Lambs	Male Lambs
		Median Days to sale	Median Days to sale
Current	Baseline	57	38
CCSM	Baseline	59	43
CCSM	Sire Weight	47	37
Hadley	Baseline	77	53
Hadley	Sire Weight	65	44
Mon Plank	Baseline	52	40
Mon Plank	Sire Weight	42	31

* 17 days is the first available sale opportunity, 108 days is the last available sale opportunity

Temora cover adaptation

Figure 39, Figure 40 and Figure 41 illustrate the response to the implementation of the 'cover' adaptation at Temora. Figure 39 illustrates the effect of implementing this adaptation on total farm gross margins. There was found to be little effect from applying the cover adaptation for all 3 GCMs. Figure 40 displays the effect of implementing the 'cover' adaptation on long term average pasture cover, showing little variation when implementing the cover adaptation. Figure 41 displays the effect of implementing the 'cover' adaptation on ewe supplementation. There does appear to be a slight decrease in the amount of supplement fed to the animals for the CCSM climate scenario, especially in March and June and Hadley also show some improvements. It is also interesting to note the difference in the distribution of supplement intake between the three future climate scenarios.

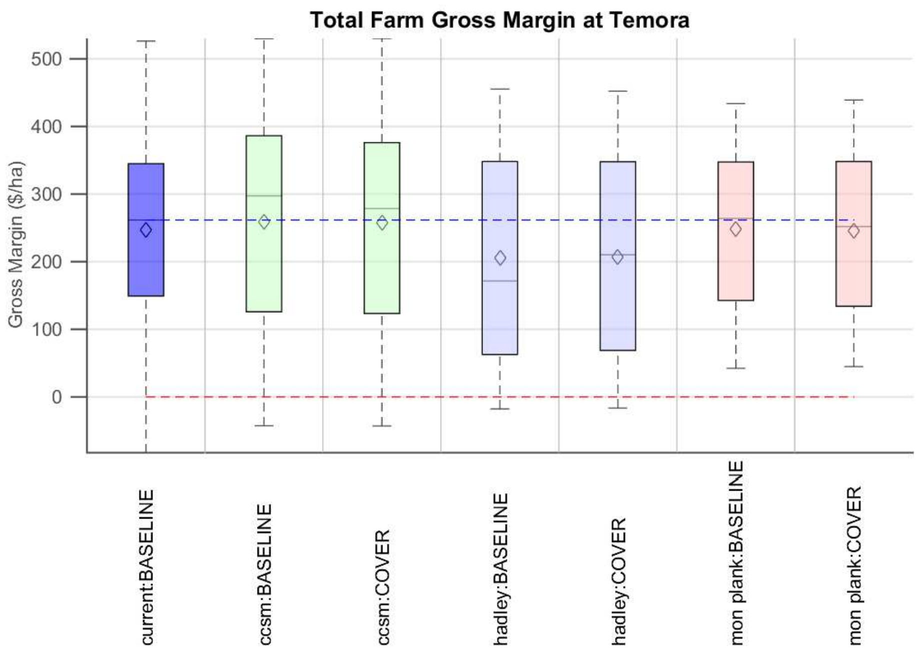

Figure 39. Total farm gross margin ($/ha) highlighting the effect of implementing the cover adaptation under different climate scenarios.

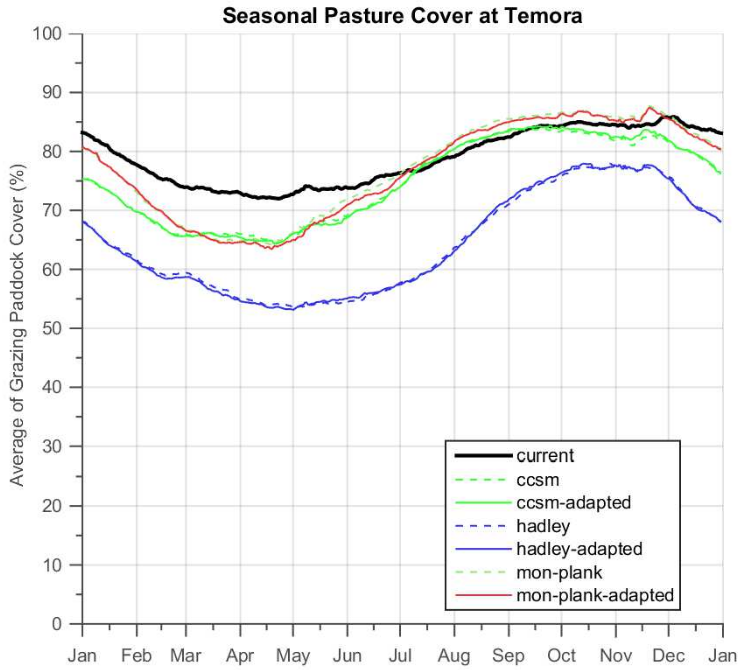

Figure 40. Long term average (%) pasture cover (aggregated to the whole farm as median across all paddocks) highlighting the effect of implementing the cover adaptation under different climate scenarios.

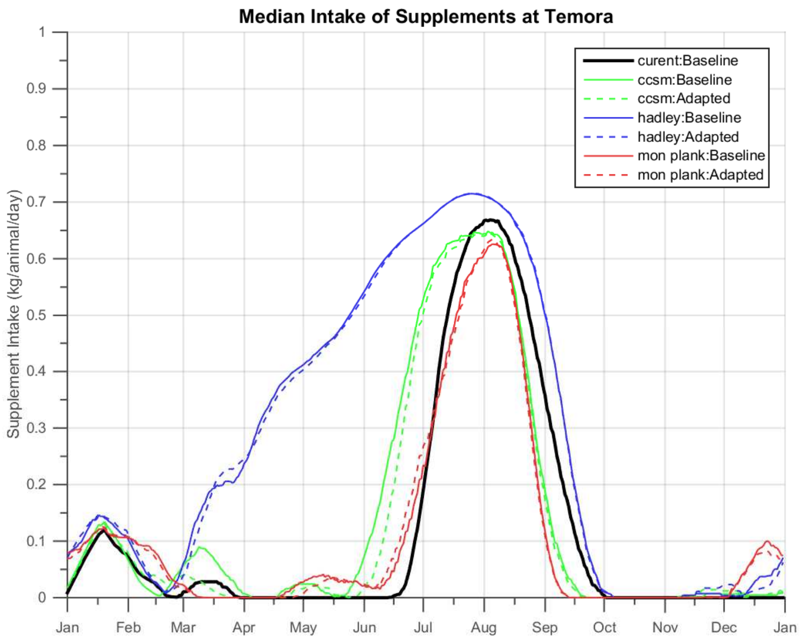

Figure 41. Long term average supplement fed to ewes (kg/head/day) highlighting the effect of implementing the cover adaptation under different climate scenarios. 'BASELINE' is current management and 'ADAPTED' is cover adaptation.

Summary – Temora

The average impact for the projected changes in Temora includes;

- slight increase in the economic return across the farm,
- a slight increase in crop yield likely driven by increased CO_2 levels and decreased water logging,
- a slight shortening of the growing season,
- a slight increase in annual pasture dry matter production,
- a slight decrease in the amount of animal supplementation required to meet livestock requirements,
- increases in ewe body weight and condition score, and
- an increased number of weaned lambs and better average condition

At the Temora site implementation of the adaptation option showed;

- the 'sow' rule decreased average gross margins at both the farm and crop level and increased the probability of lower end returns. This was driven by decreases in average yield and broadening yield probabilities.
- the 'genetics' rule slightly improved gross margins at both the farm and animal level and increased probabilities of higher end returns. This result was driven by faster finishing times from increases in lamb weight gain.
- The 'cover' rule had no notable impact on farm gross margins, seasonal pasture cover or level of supplementation required.

A detailed summary of the response of each GCM run to the 3 adaptation option can be found in Appendix 7.

Impact assessment - Condobolin

Condobolin climate

Figure 42, Figure 43 and Figure 44 show the comparison of historical and projected climatic conditions at Condobolin. Figure 42 shows the range of potential rainfall compared to historical measurements. Figure 43 shows an overall increase in both average daily maximum and minimum temperatures, with average increases of up to 2°C not uncommon. The occurrence and projected changes in winter/spring frost (Figure 44) shows a slightly higher expectancy of later season frosts. This increased incidence of later frosts has the potential to effect crop performance. A more detailed monthly statistical analysis including an assessment of rainfall and maximum temperatures can be found in Appendix 6.

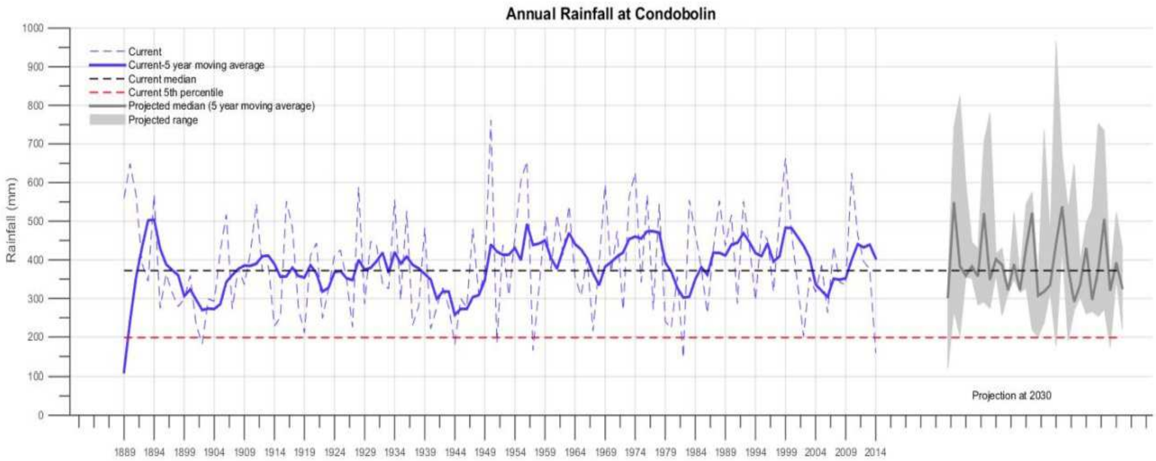

Figure 42.Long term variability in annual rainfall at Condobolin with the range of climate model projections at 2030

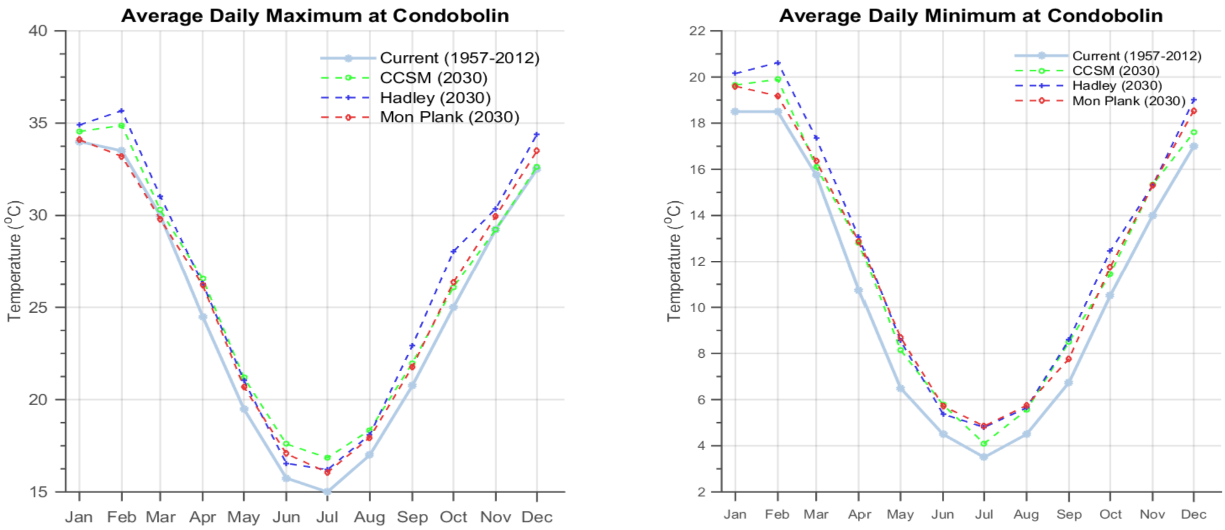

Figure 43.The maxima and minima monthly temperatures at Condobolin for current climate and the projected period (2030).

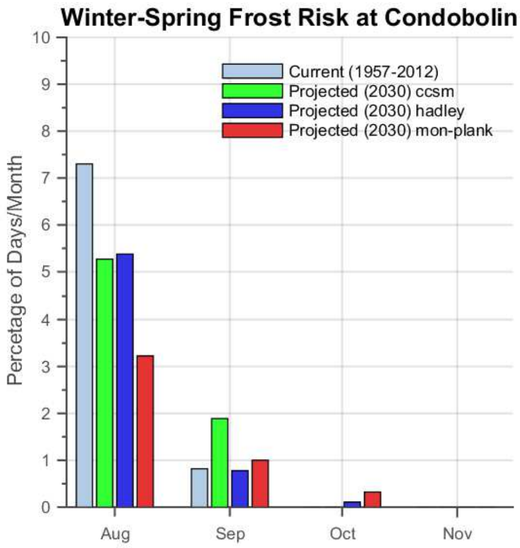

Figure 44. Late winter/spring frost risk at Condobolin, where a frost is a minimum daily temperature below 0 degrees C.

Condobolin economics

Figure 45 presents the gross margin calculations for Condobolin for the animal, crop and whole farm component of the farming enterprise, comparing historic conditions future climate scenarios (CCSM, Hadley, Mon Plank and a combined summary of the three GCMs). The results indicate a slight to moderate decrease in economic returns under future climate. When examining the crop gross margins, there does appear to be similar expected variability between the three GCMs however the Hadley GCM shows a greater chance of receiving lower end returns and a decreased probability of high end returns. This pattern is also reflected in the farm gross margin results.

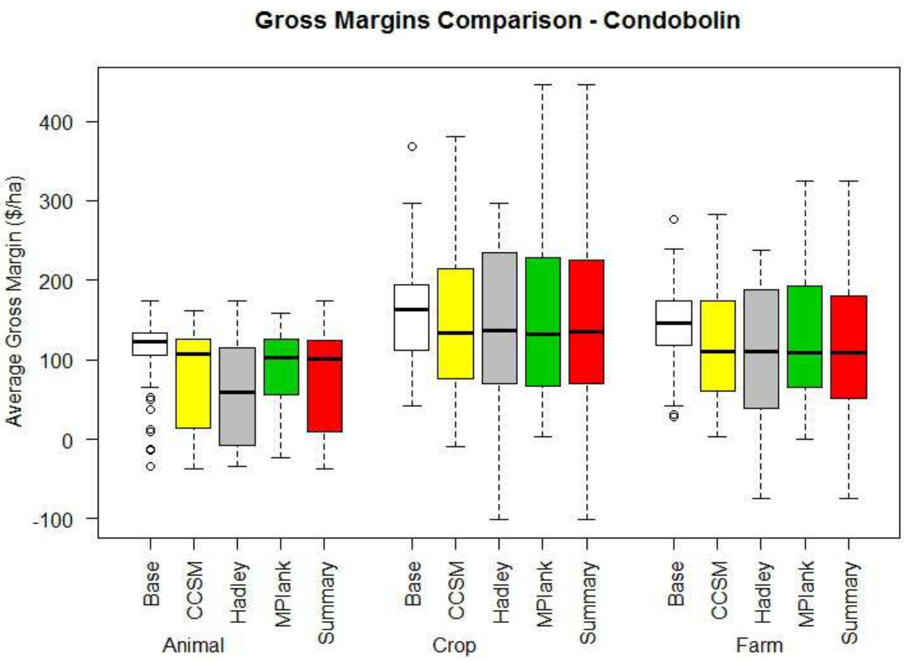

Figure 45. Condobolin site- gross margin comparison for 2030.

Condobolin crop production

Figure 46 and Figure 47 show the comparison of historical and projected crop performance under climatic conditions at Condobolin. Figure 46 presents the finding of crop yields for barley and wheat at Condobolin. It is interesting to note the differences in average crop yields expected for barley and wheat, with barley consistently performing better under the three future climate scenarios and wheat recording lower yields. This is partly explained by the rotation with wheat undersown with pasture in the year. Figure 47 presents the finding of crop harvest date for barley and wheat at Condobolin. There have been large reductions in the days to harvest across both crop types for all three GCMs

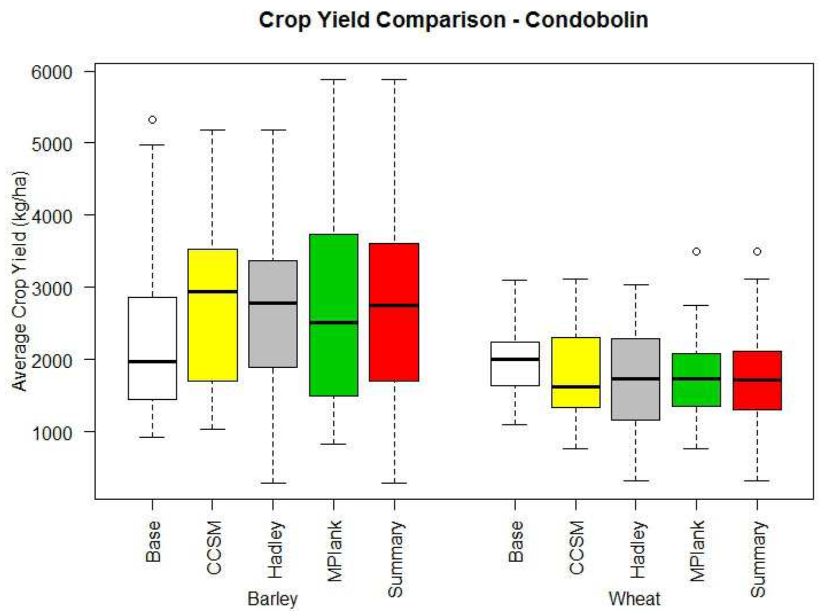

Figure 46. Condobolin site-crop yield comparison for 2030.

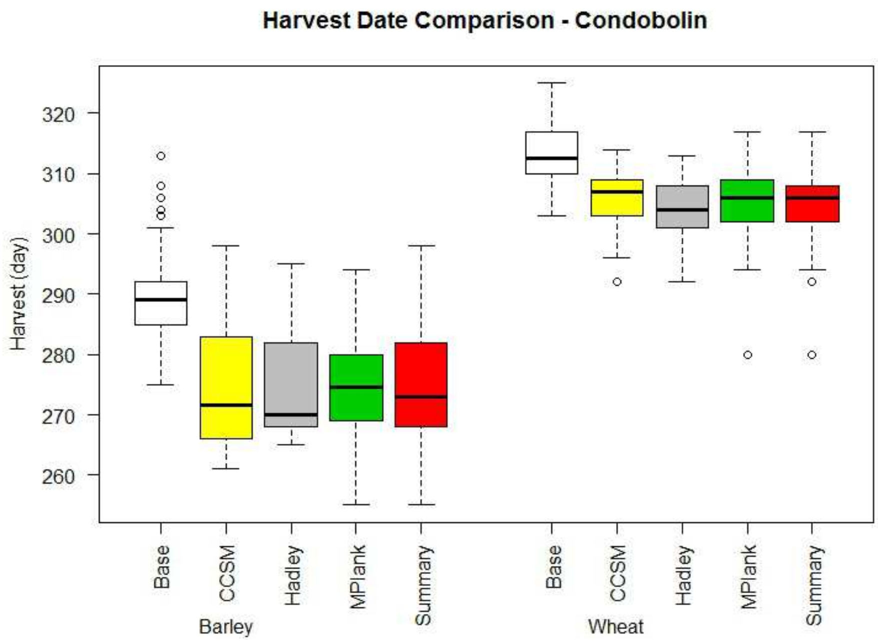

Figure 47. Condobolin site-harvest day comparison for 2030.

Condobolin pasture production

Figure 48 and Figure 49 show the comparison of historical and projected pasture performance under climatic conditions at Condobolin. Figure 48 presents the finding of total pasture dry matter at Condobolin, showing Mon Plank to be the best performing GCM and Hadley the worst performer. Figure 49 presents the findings of relative ground cover as a proportion of total pasture cover at Condobolin. Each of the three future climate scenarios shows reductions in the minimum amount of ground cover. This will have implications on how pastures are managed and the effect this will have on livestock production under future climate scenarios.

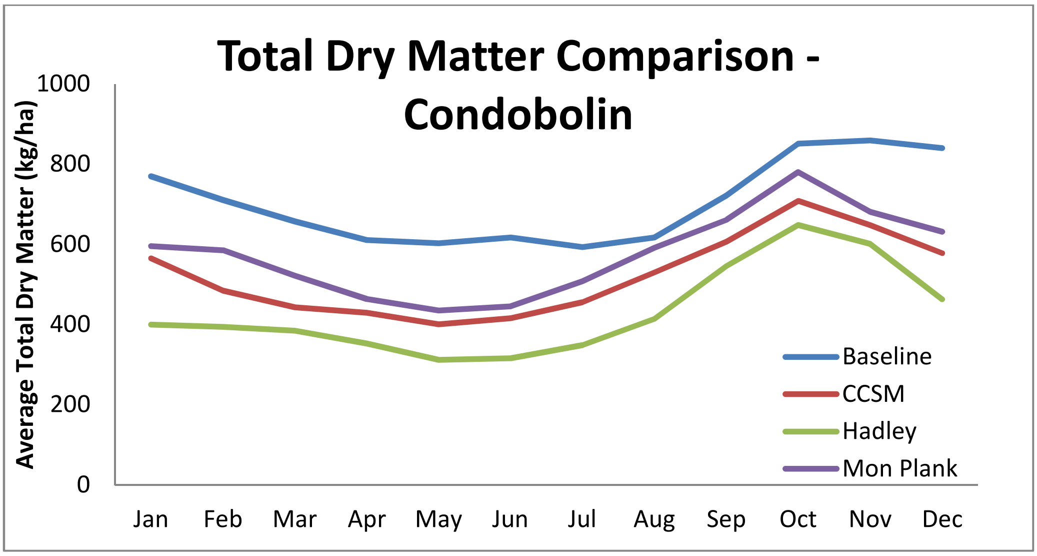

Figure 48. Condobolin site-total dry matter comparison for 2030.

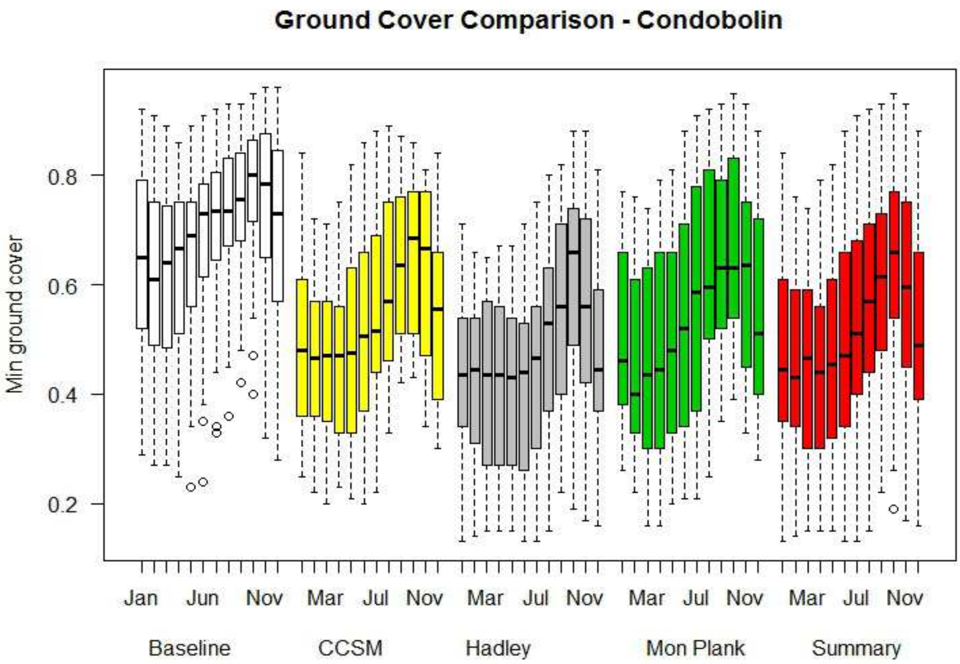

Figure 49. Condobolin site-ground cover comparison for 2030 as a proportion of cover (0-1).

Condobolin livestock production

Figure 50, Figure 51 and Table 12 show the comparison of historical and projected animal performance under climatic conditions at Condobolin. Figure 50 shows the response to the amount of annual ewe supplementation required, where all three GCMs have an increase in supplementary feed intake. This increase feed demand is also supported by the finding in Figure 48, relating to the amount of total dry matter available. This increase would have implications on gross margins for both the livestock component and whole farm component of the farming system. Figure 51 presents the findings of average ewe weight at Condobolin, which shows Hadley to be the worst performing GCM and Mon Plank the best. Table 12 presents the findings of average lamb performance at Condobolin. When compared to baseline, each of the three GCMs show expected reductions in the number of lambs in the system, drops in lamb weights and condition. Across all three variables, the Hadley GCM restricts production the most.

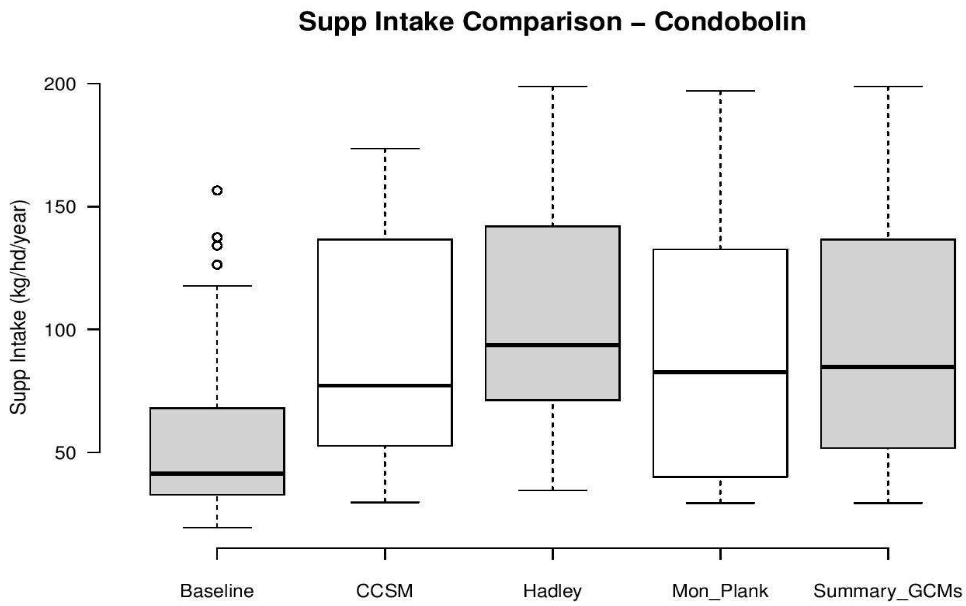

Figure 50. Condobolin site-supplementary feed intake comparison for 2030.

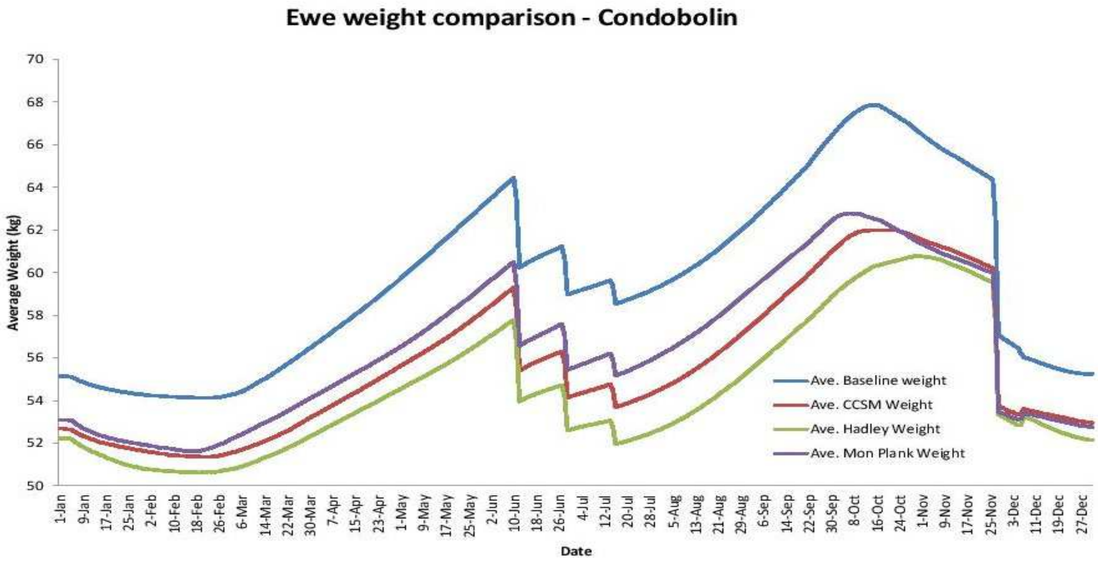

Figure 51. Condobolin site-ewe weight comparison for 2030.

Table 12. Condobolin site-lamb performance comparison for 2030.

Climate Scenario	Ave. Number of lambs	Ave. Max weight (kg)	Ave. Max Condition score
Baseline (No.)	1136	43.46	3.35
CCSM (% change)	-1.4	-7.8	-13.4
Hadley (% change)	-5.1	-13.1	-20.0
Mon Plank (% change)	-1.3	-8.6	-10.7
Average 3 GCMs (% change)	-2.6	-9.8	-14.7

Adaptation assessment - Condobolin

Condobolin sowing adaptation

Figure 52 and Figure 53 present the economic response to implementation of the 'sowing' rule at Condobolin under the 3 future climate scenarios. Figure 52 illustrates the effect of implementing the 'sowing' rule on total farm gross margins and Figure 53 illustrates the effect of the implementing the 'sowing' rule on crop gross margins. Both figures show the variations of future climate scenarios (CCSM, Hadley & Mon Plank) compared to historic conditions (baseline). Implementing the sowing rule has seen increase in the average farm gross margin returns for each of the GCMs, along with a decrease in the probability of lower end returns (Figure 52). When examining the effects of the sowing adaptation has on crop gross margins, only slight differences were found, though there was a reduction in the probability of receiving lower end returns (most noticeable in the CCSM climate scenario).

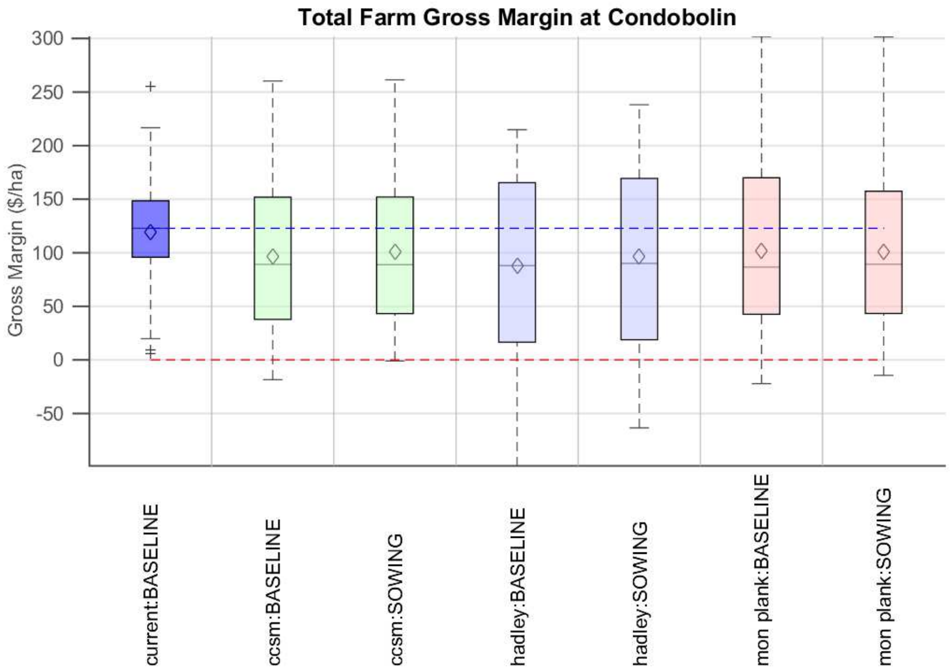

Figure 52. Total farm gross margin ($/ha) highlighting the effect of implementing the sowing adaptation under different climate scenarios.

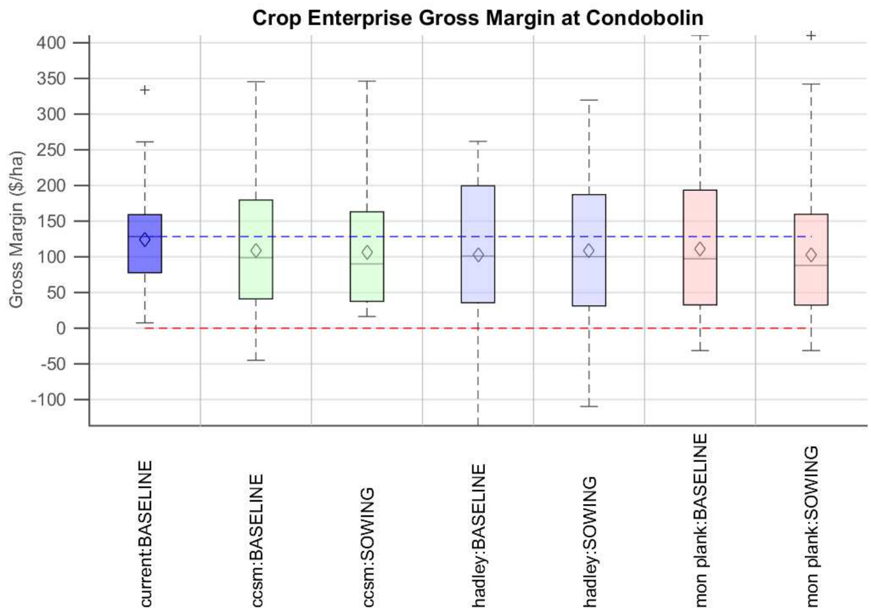

Figure 53. Crop gross margin ($/cropped ha) highlighting the effect of implementing the sowing adaptation under different climate scenarios.

Figure 54 illustrates the effect on crop yield of implementing the 'sowing' rule on each of the three species represented at Condobolin. When examining individual crops, there is slightly positive improvement in median yields for both barley and wheat under the sowing adaptation.

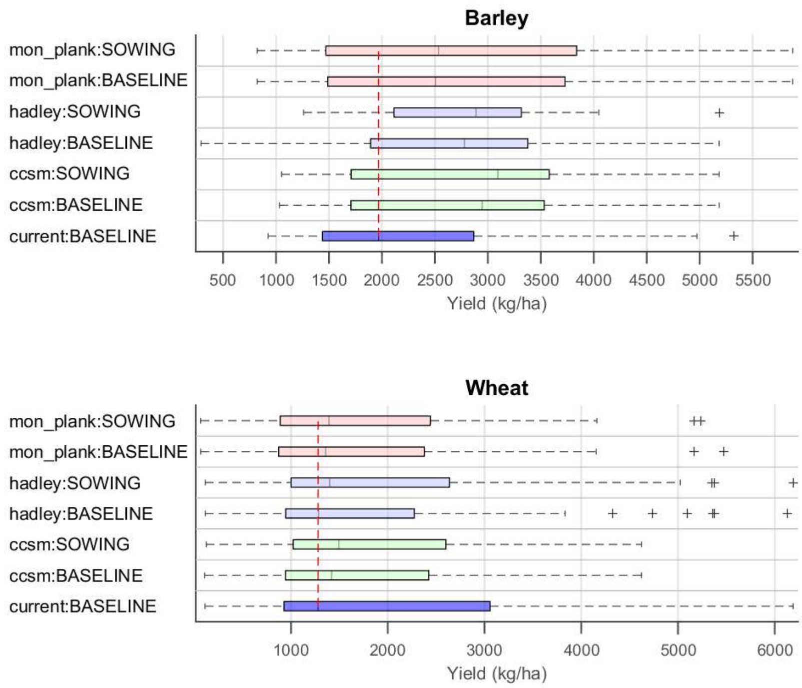

Figure 54. Crop yields (kg/ha) highlighting the effect of implementing the sowing adaptation under different climate scenarios.

Table 13 provides a summary of the number of years when the 'sowing' adaptation was triggered under the future climate scenario. CCSM and Hadley were the most affected by the sowing adaptation, though this rule only affected a small percentage of years. Mon Plank showed the least change from baseline due to the sowing adaptation. It is also important to consider the number of years that the final crop in the rotation (wheat) was not sown. This has implications for the pasture phase of the farming system a pasture was undersown with wheat, resulting in no pasture being sown and therefore reducing the access livestock have to pasture paddocks for the following three years.

Table 13. The number of years that the sowing adaptation was enacted.

Effect of Sowing Adaptation	CCSM	Hadley	Mon Plank
Number of years barley was not sown	2 (8%)	2 (8%)	0
Number of years last rotation (wheat) was not sown*	1 (4%)	1 (4%)	1 (4%)
Number of years no crops were sown	0	0	0
Number of years only one crop was sown	1 (4%)	1 (4%)	0

* reducing the number of paddocks in pasture for the next three years (placed into a fallow instead)

Condobolin genetics adaptation

Figure 55 and Figure 56 present the economic response to implementation of the 'genetics' adaptation at Condobolin under the 3 future climate scenarios. Figure 55 illustrates the effect of implementing the 'genetics' adaptation on total farm gross margins. There appears to be little effect on the gross margins across all 3 GCMs due to the genetics adaptation. Figure 56 illustrates the effect of the implementing the 'genetics' adaptation on livestock gross margins. The genetics adaptation has had a varying effect on livestock gross margins, with CCSM performing slightly better and Mon Plank slightly worse.

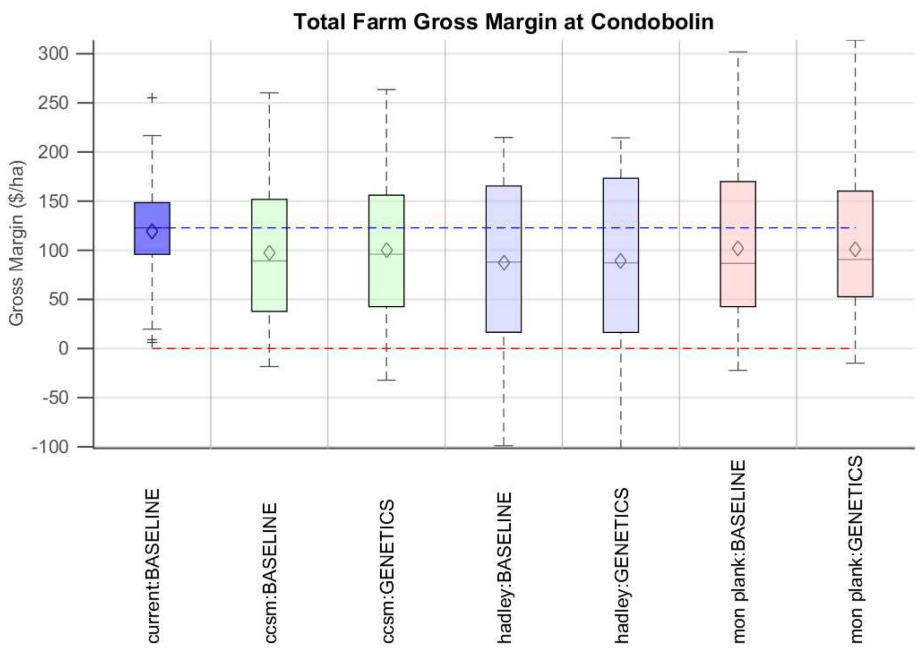

Figure 55. Total farm gross margin ($/ha) highlighting the effect of implementing the genetics adaptation under different climate scenarios.

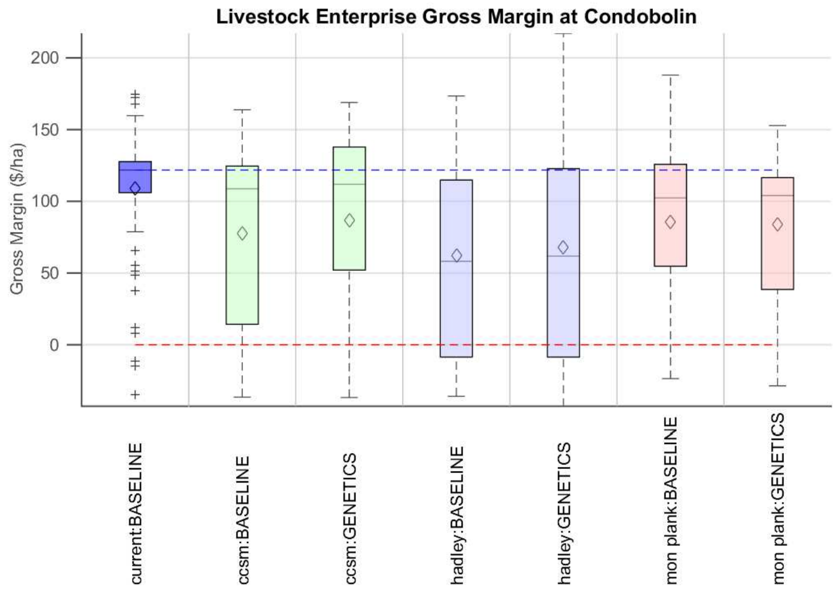

Figure 56. Livestock enterprise gross margin ($/grazed ha) highlighting the effect of implementing the genetics adaptation under different climate scenarios.

Figure 57 and Table 14 present the change in lamb performance from implementation of the 'genetics' adaptation at Condobolin. Figure 57 displays the response in lamb weight to implementation of the 'genetics' adaptation. All 3 GCMs showed noticeable positive response to the genetics adaptation. Table 14 displays the comparison in the number of days from lamb weaning to sale from implementation of the 'genetics' adaptation. All 3 GCMs were found to respond positively to the genetics adaptation, with lambs reaching sale criteria quicker than their corresponding GCM baseline. Reaching sale criteria quicker allows the opportunity better manage the flock in response to available feed in poor years, removing them from the system and therefore reducing the pressure on the pastures.

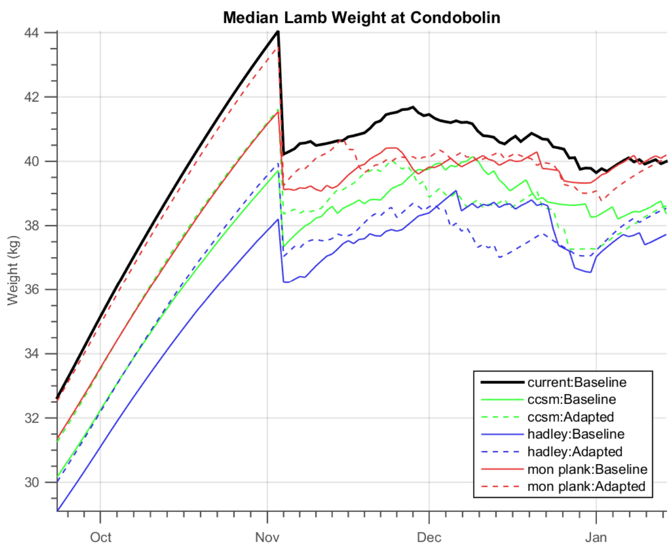

Figure 57. Median lamb weight (kg/animal) highlighting the effect of implementing the genetics adaptation under different climate scenarios.

Table 14. Number of days from lamb weaning to sale date.

Climate	Adaptation	Female Lambs	Male Lambs
		Median Days to sale	Median Days to sale
Current	Baseline	58	44
CCSM	Baseline	72	52
CCSM	Sire Weight	64	48
Hadley	Baseline	75	55
Hadley	Sire Weight	62	50
Mon Plank	Baseline	66	49
Mon Plank	Sire Weight	57	47

* 42 days is the first available sale opportunity, 114 days is the last available sale opportunity

Condobolin cover adaptation

Figure 58, Figure 59 and Figure 60 illustrate the response to the implementation of the 'cover' adaptation at Condobolin. Figure 58 illustrates the effect of implementing the 'cover' adaptation on total farm gross margins. There was found to be little effect from applying the cover adaptation for all three GCMs. Figure 59 displays the effect of implementing the 'cover' adaptation on long term average pasture cover. Only the CCSM climate scenario appears sensitive to the adaptation and only in autumn. Figure 60 displays the effect of implementing the 'cover' adaptation on ewe supplementation. There does appear to be a slight decrease in supplementation and slight shift to feeding earlier in the winter.

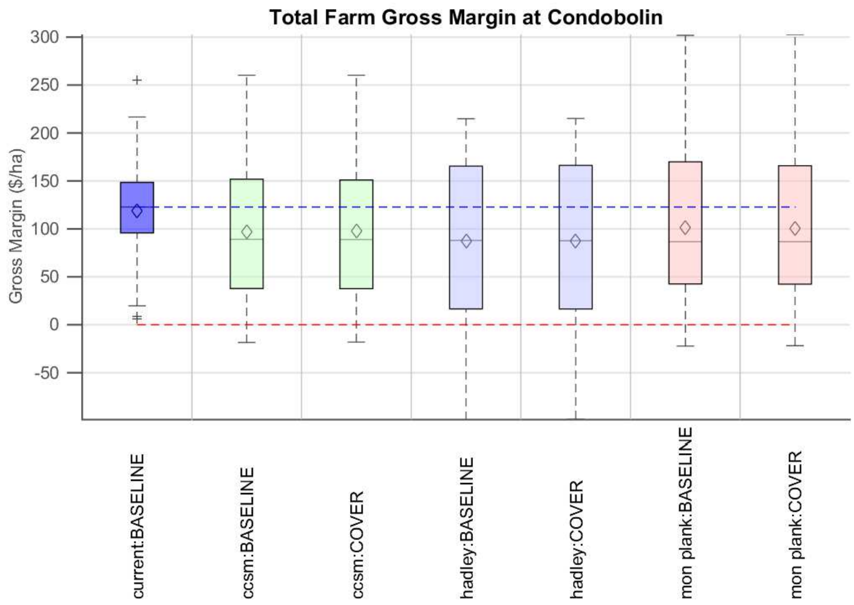

Figure 58. Total farm gross margin ($/ha) highlighting the effect of implementing the cover adaptation under different climate scenarios.

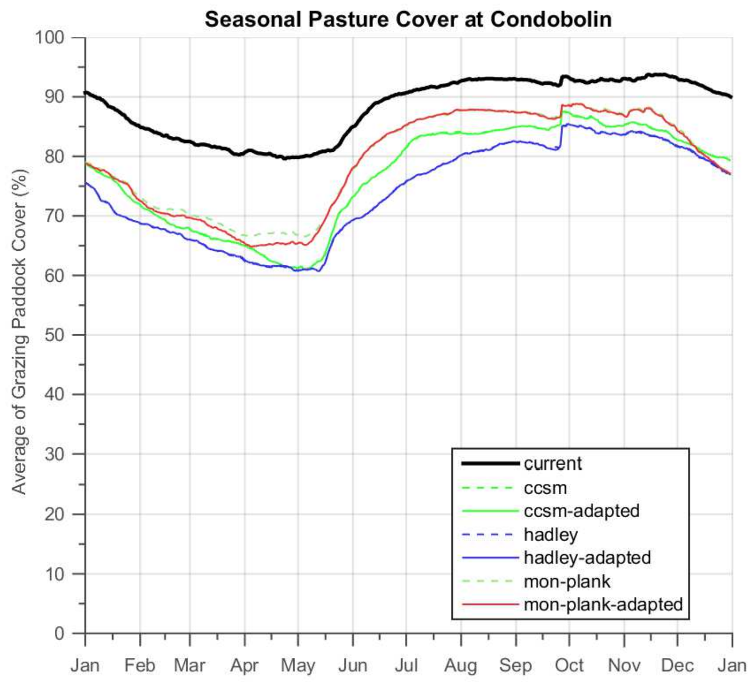

Figure 59. Long term average (%) pasture cover (aggregated to the whole farm as median across all paddocks) highlighting the effect of implementing the cover adaptation under different climate scenarios.

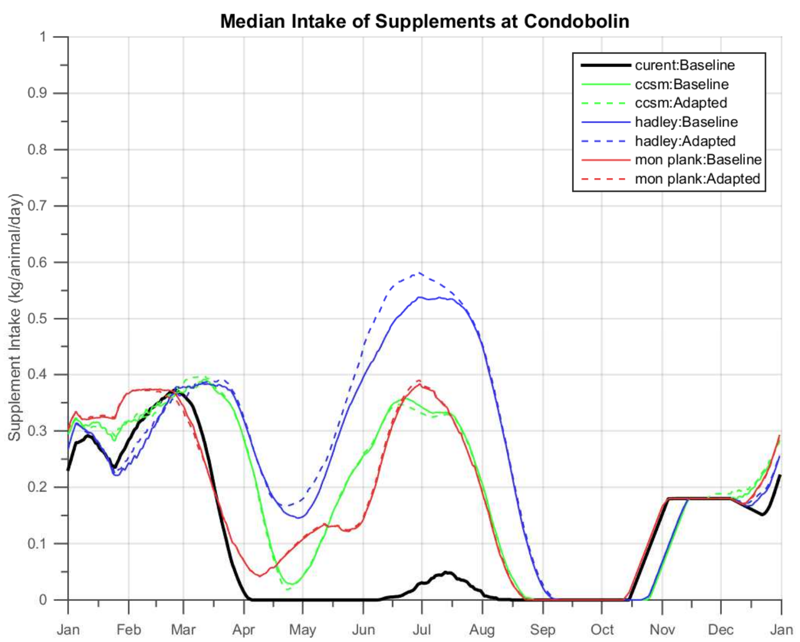

Figure 60. Long term average supplement fed to ewes (kg/head/day) highlighting the effect of implementing the cover adaptation under different climate scenarios.

Summary – Condobolin

The average impact for the project change for Condobolin includes;

- slight to moderate decrease of economic return,
- a slight decrease in crop yield at least in part driven by a shortening of the growing season (exception being barley),
- decrease in annual pasture dry matter production and slight change in seasonality ,
- moderate increase in the amount of animal supplementation required to meet livestock requirements,
- decrease in ewe body weight and condition score, and
- a decreased number of weaned lambs and lower average condition.

At the Condobolin site implementation of the adaptation option showed;

- the 'sow' rule slightly improved gross margins at both the farm and crop level and decreased the probability of lower end returns. This was driven by slight increases in average yield.
- the 'genetics' rule slightly improved gross margins at both the farm and animal level and decreased probabilities of lower end returns. This result was driven by slightly faster finishing times from increases in lamb weight gain.
- The 'cover' rule had no notable impact on farm gross margins, seasonal pasture cover or level of supplementation required.

A detailed summary of the response of each GCM run to the 3 adaptation option can be found in Appendix 7.

Conclusions

Analysis using the three GCM's provides an indication of the range of change that could occur and its potential biophysical and economic impact on mixed farms in the Riverina and Central West LLS region. The Hadley model appeared to be the driest and Mon Plank the wettest models. Whilst there is strong consistency between the models in the direction of temperature change, the CCSM and Hadley models indicate stronger warming than the Mon Plank model. Interestingly across all farms the GCM's suggest increases in average maximum and minimum temperatures in addition to an increase in the standard deviation, indicating more temperature extremes compared to the baseline period. As a consequence the biophysical and economic performance of the farms was differentially affected with the warmer drier sites at Goolgowi and Condobolin being negatively impacted but Temora positively affected.

Across the 3 GCMs the average impact of the projected change for the Goolgowi and Condobolin sites included a;

- slight to moderate decrease of economic return across the two farms,
- a slight decrease in crop yield at least in part driven by a shortening of the growing season (exception being barley),
- decrease in annual pasture dry matter production and slight change in seasonality ,
- moderate increase in the amount of animal supplementation required to meet livestock requirements,
- decrease in ewe body weight and condition score, and
- decreased number of weaned lambs and lower average condition.

Across the 3 GCMs the average impact of the projected change for the Temora site includes a;

- slight increase in the economic return across farm,
- a slight increase in crop yield likely driven by increase CO_2 levels and decreased water logging,
- a slight shortening of the growing season,
- a slight increase in annual pasture dry matter production,
- slight decrease in the amount of animal supplementation required to meet livestock requirements,
- increases in ewe body weight and condition score, and
- increased number of weaned lambs and better average condition

In consultation with LLS staff, 3 adaptation options were assessed for each of the 3 sites. The first was a 'sowing' adaptation which enabled a deviation from the baseline system, which sowed crops dry at the end of multiple sowing windows. Applying the 'sowing' option tested the impact of not sowing crops in such circumstance. The second was a 'genetics' option which tested the impact of increasing lamb weights through genetic selection and the third was a 'cover' option, testing the impact of lowering ground cover thresholds to maintain stock in paddocks for longer.

Results from the biophysical and economic adaptation assessment suggest that both Goolgowi and Condobolin sites had similar responses to the 3 adaptations assessed i.e. 'sowing', 'genetics' and ‘cover’ whilst Temora in contrast had a very different response. Broadly speaking the negative impacts on biophysical and economic performance at the Goolgowi and Condobolin sites from the future climate scenarios can in part be countered by incremental adaptation, altering ‘sowing’ and animal ‘genetics’, The Temora site by contrast was negatively affected by altering the ‘sowing’ rule and only had a small positive response from improving animal ‘genetics’ compared to the other sites. The ‘cover’ adaptation appeared to offer little upside across all sites.

At the Goolgowi site implementation of:

- the ‘sow’ rule improved gross margins at both the farm and crop level and decreased the probability of lower end returns. This was driven by increases in average yield and tightening yield probabilities.
- the ‘genetics’ rule improved gross margins at both the farm and animal level and increased probabilities of higher end returns. This result was driven by faster finishing times from increases in lamb weight gain.
- The ‘cover’ rule had no notable impact on farm gross margins, seasonal pasture cover or level of supplementation required.

At the Temora site implementation of:

- the ‘sow’ rule decreased average gross margins at both the farm and crop level and increased the probability of lower end returns. This was driven by decreases in average yield and broadening yield probabilities.
- the ‘genetics’ rule slightly improved gross margins at both the farm and animal level and increased probabilities of higher end returns. This result was driven by faster finishing times from increases in lamb weight gain.
- The ‘cover’ rule had no notable impact on farm gross margins, seasonal pasture cover or level of supplementation required.

At the Condobolin site implementation of:

- the ‘sow’ rule slightly improved gross margins at both the farm and crop level and decreased the probability of lower end returns. This was driven by slight increases in average yield.
- the ‘genetics’ rule slightly improved gross margins at both the farm and animal level and decreased probabilities of lower end returns. This result was driven by slightly faster finishing times from increases in lamb weight gain.
- The ‘cover’ rule had no notable impact on farm gross margins, seasonal pasture cover or level of supplementation required.

Future considerations

This assessment should be viewed as a snapshot in time which was based on the best and most suitable climate data and future projections available at the time, but also limited by the investigators capacity to accurately represent local farming systems using the biophysical and economics models available. However, even given these limitations, a significant legacy now exists in simulation development for mixed farming systems. Options for further work would include a:

- rapid reassessment of biophysical and economic impact and adaptation using the Office of Environment and Heritages (OEH's) NARCLIM dataset,
- assessment of applying both the 'sowing' and 'genetic' adaptations simultaneously,
- assessment of increasing sire weights further for the 'genetic' adaptation to further test the sensitivity of the farming system,
- broader economic assessment including balance sheet assessment,
- inclusion of irrigation, and
- assessment of optimal enterprise mix.

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Appendices

Appendix 1. Biophysical model descriptors

APSIM

The ***A****gricultural* ***P****roduction* ***S****ystems s****IM****ulator (APSIM) software is a modular modelling framework that has been developed by the APSIM Initiative and its predecessor the Agricultural Production Systems Research Unit (APSRU) in Australia. APSIM was developed to simulate biophysical processes in agricultural systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk.*

APSIM is structured around plant, soil and management modules. These modules include a diverse range of crops, pastures and trees, soil processes including water balance, nitrogen and phosphorous transformations, soil pH, erosion and a full range of management controls. APSIM resulted from a need for tools that provided accurate predictions of crop production in relation to climate, genotype, soil and management factor while addressing the long-term resource management issues (Source:http://www.apsim.info/AboutUs/APSIMModel.aspx).

GrassGro

GrassGro is a decision support tool developed by CSIRO Plant Industry to assist decision-making in sheep and beef enterprises. By quantifying the variability in pasture and animal production, farmers and natural resource managers can assess the risks that variable weather imposes on a grazing system. Users can test management options against a wide range of seasons to achieve more profitable and sustainable utilisation of grasslands.

GrassGro is a computer program that delivers grazing systems research in a useable form to farmers and their advisers. GrassGro is based on decades of field experimentation from across Australia and lets the user focus on the biophysical and business outcomes of management decisions. Behind GrassGro™s interface, inputs of historical daily weather data drive models of the interacting processes of pasture growth and animal production. Day-to-day changes in water content of soil, pasture growth and decay and responses to grazing are simulated for a chosen enterprise. The user describes their livestock, management, costs and prices. The animal model familiar to users of the decision support tool GrazFeed is built into GrassGro to predict animal intake and production of wool, meat and milk. Seasonal and year-to-year variation in pasture and animal production and gross margins are presented in comprehensive reports for analysis of risk. (Source http://www.grazplan.csiro.au/?q=node/1)

AusFarm

AusFarm's structure allows models of farm components to be configured and co-ordinated with an infinitely flexible set of management rules. The modular design of the software means it can include models from other scientific groups. This greatly expands the number of crop, livestock and management systems that can be represented and analysed compared to GrassGro for example. AusFarm is primarily intended for research into and analysis of agro-ecosystems.
CSIRO Plant Industry has used the Common Modelling Protocol to develop AusFarm, a generic simulation tool for agricultural enterprises that is designed to facilitate the analysis of complex agricultural management questions. The AusFarm interface allows a user to configure simulations for execution within the Common Modelling Protocol. Management activities are conceptualized as a set of "events" that alter the state of a sub-model; the series of events that takes place in a simulation is governed by rules that describe conditions under which management events will take place. (Source http://www.hzn.com.au/ausfarm.php)

Appendix 2. Farming systems literature

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Appendix 3. Detailed assumptions for the AusFarm case study sites

Goolgowi site assumptions

Farm area (ha)	4000
No. of paddocks	8
Pasture type	Lucerne, medic and sub clover
Stocking rate	0.3
No. ewes	1200
Ewes	Medium Merino
Sire	Dorset

Crop	Variety	Sowing Window	Rainfall	Soil moisture	Surface moisture	Density	Depth	Spacing
Wheat	Gladius	30-Apr	0	25	5	90	25	150
Wheat	Axe	30 April – 14 June	15	0	0	90	25	150
Barley	Hindmarsh	30-Apr	0	25	5	40	25	150
Barley	Hindmarsh	30 April – 14 June	15	0	0	40	25	150
Canola	Oscar	31-Mar	0	25	5	50	10	150
Canola	Oscar	31 March – 30 May	15	0	500	50	10	150

Temora site assumptions

Farm area (ha)	2000
No. of paddocks	10
Pasture type	Lucerne and sub clover
Stocking rate	1.5
No. ewes	3000
Ewes	Medium Merino
Sire	Dorest

Crop	**Variety**	**Sowing Window**	**Rainfall**	**Soil moisture**	**Surface moisture**	**Density**	**Depth**	**Spacing**
Wheat	Wedgetail	23 March – 6 May	25	25	5	130	25	180
Wheat	Janz	7 May – 8 June	15	0	0	130	25	180
Canola	Oscar	31 March – 14 May	25	25	5	50	10	180
Canola	Oscar	31 March – 14 May	15	0	0	50	10	180
Barley	Gairdner	19 April – 29 June	0	25	5	130	25	180
Wheat(p)	Janz	24 April – 30 May	15	0	0	50	25	180

Condobolin site assumptions

Farm area (ha)	4000
No. of paddocks	8
Pasture type	Lucerne, medic and sub clover
Stocking rate	0.3
No. ewes	1200
Ewes	Medium Merino
Sire	Dorest

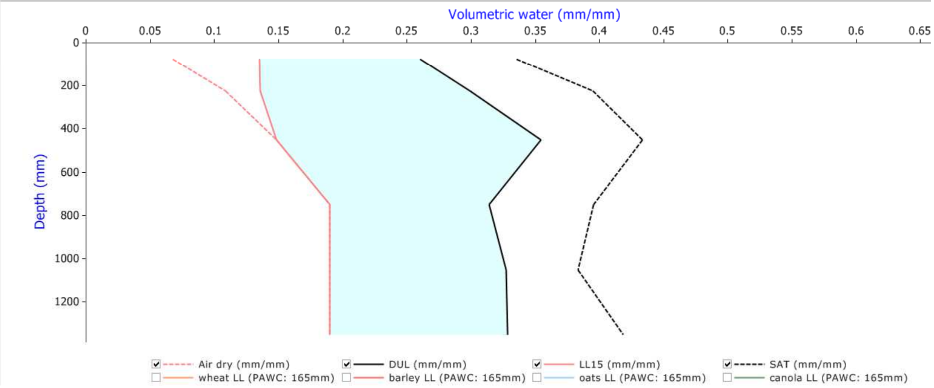
Crop	Variety	Sowing Window	Rainfall	Soil moisture	Surface moisture	Density	Depth	Spacing
Wheat	Wedgetail	31 March – 30 April	0	25	5	100	25	150
Wheat	Gladius	1 May – 21 May	15	0	0	100	25	150
Wheat	Axe	22 May – 21 June	10	0	0	100	25	150
Barley	Gairdner	24 April – 20 May	0	25	5	100	25	150
Barley	Hindmarsh	21 May – 13 June	10	0	0	100	25	150

Appendix 4. Reference site soil water summary

Goolgowi

The table and accompanying graph summarises site specific soil water content levels and species specific soil water availability.

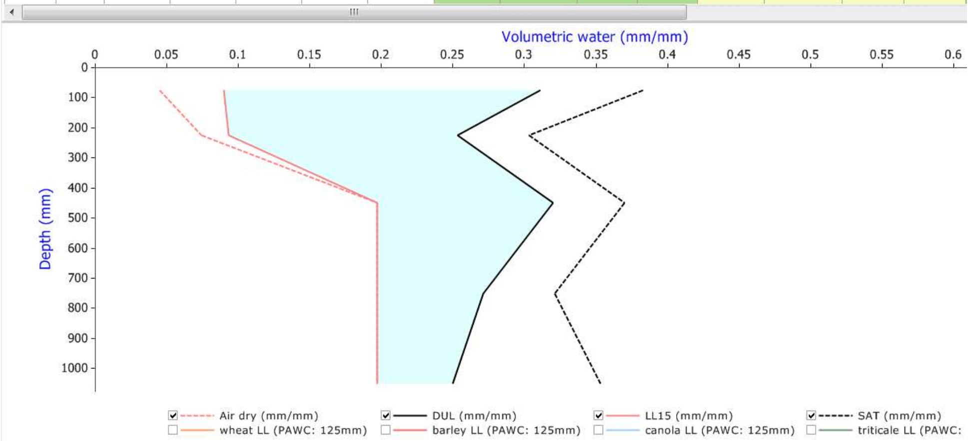
Depth (cm)	BD (g/cc)	AirDry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	KS (mm/day)	wheat LL (mm/mm)	wheat PAWC 165.0	wheat KL (/day)	wheat XF (0-1)	barley LL (mm/mm)	barley PAWC 165.0	barley KL (/day)	barley XF (0-1)
0-15	1.682	0.068	0.135	0.260	0.335		0.135	18.8	0.06	1.0	0.135	18.8	0.07	1.0
15-30	1.524	0.108	0.135	0.299	0.395		0.135	24.5	0.06	1.0	0.135	24.5	0.07	1.0
30-60	1.422	0.148	0.148	0.354	0.434		0.148	61.8	0.06	1.0	0.148	61.8	0.07	1.0
60-90	1.523	0.190	0.190	0.314	0.395		0.190	37.3	0.04	1.0	0.190	37.3	0.05	1.0
90-120	1.555	0.190	0.190	0.327	0.383		0.289	11.3	0.04	1.0	0.289	11.3	0.05	1.0
120-150	1.461	0.190	0.190	0.328	0.419		0.290	11.4	0.02	1.0	0.290	11.4	0.03	1.0



Temora

The table and accompanying graph summarises site specific soil water content levels and species specific soil water availability.

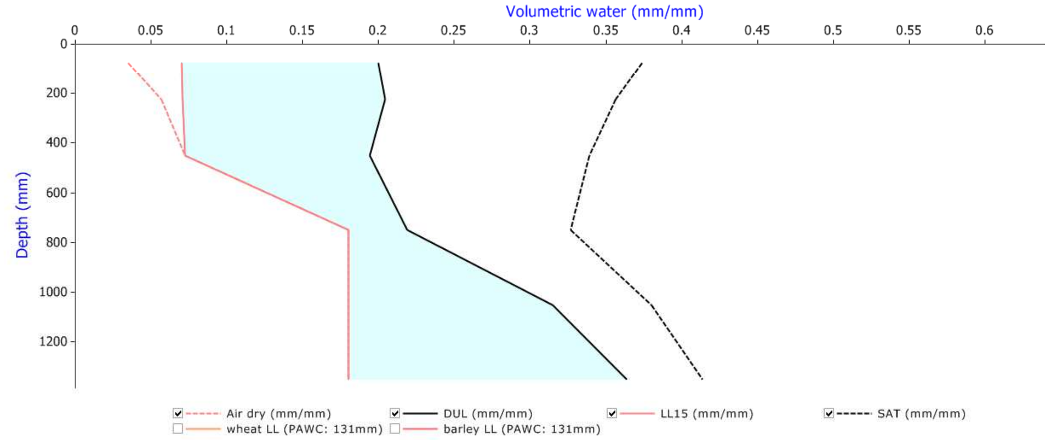
Depth (cm)	BD (g/cc)	AirDry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	KS (mm/day)	wheat LL (mm/mm)	wheat PAWC 125.0	wheat KL (/day)	wheat XF (0-1)	barley LL (mm/mm)	barley PAWC 125.0	barley KL (/day)	barley XF (0-1)
0-15	1.554	0.045	0.090	0.311	0.383		0.090	33.2	0.06	1.0	0.090	33.2	0.07	1.0
15-30	1.768	0.074	0.093	0.253	0.303		0.093	24.0	0.06	1.0	0.093	24.0	0.07	1.0
30-60	1.589	0.197	0.197	0.320	0.370		0.199	36.3	0.06	1.0	0.199	36.3	0.07	1.0
60-90	1.719	0.197	0.197	0.271	0.321		0.206	19.5	0.04	1.0	0.206	19.5	0.05	1.0
90-120	1.635	0.197	0.197	0.250	0.353		0.210	12.0	0.04	1.0	0.210	12.0	0.05	1.0



Condobolin

The table and accompanying graph summarises site specific soil water content levels and species specific soil water availability.

Depth (cm)	BD (g/cc)	AirDry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	KS (mm/day)	wheat LL (mm/mm)	wheat PAWC 131.4	wheat KL (/day)	wheat XF (0-1)	barley LL (mm/mm)	barley PAWC 131.4	barley KL (/day)	barley XF (0-1)
0-15	1.580	0.035	0.070	0.200	0.374		0.070	19.5	0.06	1.0	0.070	19.5	0.07	1.0
15-30	1.625	0.056	0.071	0.204	0.357		0.071	20.1	0.06	1.0	0.071	20.1	0.07	1.0
30-60	1.672	0.072	0.072	0.194	0.339		0.072	36.5	0.06	1.0	0.072	36.5	0.07	1.0
60-90	1.705	0.180	0.180	0.219	0.327		0.180	11.6	0.04	1.0	0.180	11.6	0.05	1.0
90-120	1.563	0.180	0.180	0.315	0.380		0.248	20.0	0.04	1.0	0.248	20.0	0.05	1.0
120-150	1.474	0.180	0.180	0.364	0.414		0.285	23.7	0.02	1.0	0.285	23.7	0.03	1.0



Appendix 5. Baseline and projected biophysical and economic impact

Goolgowi

Table A5.1 Goolgowi site-Baseline harvest date (average) for each crop and the variance (percent change) for the three GCMs

	Crop		
Climate Scenario	**Barley**	**Canola**	**Wheat**
Baseline	23 Oct	16 Oct	09 Nov
CCSM (% change)	-4	-4	-4
Hadley (% change)	-3	-2	-4
Mon Plank (% change)	-4	-3	-4
Average 3 GCMs (% change)	-4	-3	-4

Table A5.2 Goolgowi site-Baseline gross margins (average) for each system and the variance (percent change) for the three GCMs

	System		
Climate Scenario	**Animal**	**Crop**	**Farm**
Baseline ($)	$114.63	$464.86	$333.53
CCSM (% change)	-11	-28	-26
Hadley (% change)	-44	-38	-39
Mon Plank (% change)	-11	-14	-13
Average 3 GCMs (% change)	-22	-27	-26

Table A5.3 Goolgowi site-Baseline monthly total dry mater (average) and the variance (percent change) for the three GCMs

	Month											
Climate Scenario	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Baseline (kg/ha)	633.2	577.8	546.7	522.3	532.0	558.5	580.5	658.4	800.9	867.6	785.1	698.0
CCSM (% change)	-20	-23	-27	-26	-25	-22	-15	-6	-9	-19	-21	-20
Hadley (% change)	-39	-40	-43	-44	-47	-48	-46	-37	-32	-34	-34	-36
Mon Plank (% change)	-4	-3	-10	-11	-12	-11	-1	4	-2	-6	-3	-6
Average 3 GCMs (% change)	-21	-22	-27	-27	-28	-27	-21	-13	-15	-19	-19	-20

Table A5.4 Goolgowi site-Baseline monthly and overall groundcover (average) and the variance (percent change) for the three GCMs

Climate Scenario	Month												Overall
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**(years)**
Baseline (%)	43	63	57	63	61	68	75	79	79	59	43	38	16
CCSM (% change)	-64	-63	-60	-69	-37	-49	-33	-31	-31	-28	-46	-59	-76
Hadley (% change)	-64	-69	-80	-82	-62	-72	-59	-56	-31	-41	-55	-49	-100
Mon Plank (% change)	-37	-45	-73	-57	-56	-49	-44	-12	-31	-9	8	3	-76
Average 3 GCMs (% change)	-55	-59	-71	-69	-51	-57	-45	-33	-31	-26	-31	-35	-84

Table A5.5 Goolgowi site-Baseline ewe supplementary intake (average) and the variance (percent change) for the three GCMs

Climate Scenario	Intake (kg/head/year)		
	Total Supp	**Total Pasture**	**Total**
Baseline (kg/hd/year)	54.7	433.5	488.1
CCSM (% change)	28	-9	-5
Hadley (% change)	81	-29	-16
Mon Plank (% change)	8	-3	-2
Average 3 GCMs (% change)	39	-14	-8

Temora

Table A5.6 Temora site-Baseline harvest date (average) for each crop and the variance (percent change) for the three GCMs

Climate Scenario	Crop		
	Barley	**Canola**	**Wheat**
Baseline	26 Oct	04 Nov	19 Nov
CCSM (% change)	-5	-2	-2
Hadley (% change)	-4	-2	-2
Mon Plank (% change)	-4	-3	-2
Average 3 GCMs (% change)	-4	-2	-2

Table A5.7 Temora site-Baseline gross margins (average) for each system and the variance (percent change) for the three GCMs

Climate Scenario	System		
	Animal	Crop	Farm
Baseline ($)	$258.93	$233.64	$246.28
CCSM (% change)	-5	16	5
Hadley (% change)	-34	3	-16
Mon Plank (% change)	-6	9	1
Average 3 GCMs (% change)	-15	9	-3

Table A5.8 Temora site-Baseline monthly total dry mater (average) and the variance (percent change) for the three GCMs

Climate Scenario	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline (kg/ha)	571	532	497	473	579	674	758	840	1058	1402	108	679
CCSM (% change)	12	-1	-4	6	-9	-10	-3	10	14	-1	-8	9
Hadley (% change)	-47	-47	-53	-52	-51	-52	-47	-33	-17	-13	-16	-28
Mon Plank (% change)	1	9	15	22	17	8	13	29	29	9	-3	-5
Average 3 GCMs (% change)	-11	-13	-14	-8	-14	-18	-13	2	9	-1	-9	-8

Table A5.9 Temora site-Baseline monthly and overall groundcover (average) and the variance (percent change) for the three GCMs

Climate Scenario	Month												Overall (years)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Baseline (%)	59	55	59	59	64	71	71	79	84	89	79	68	36
CCSM (% change)	-22	-24	-22	-15	-22	-14	2	-2	1	-10	-22	-21	-46
Hadley (% change)	-54	-51	-54	-74	-70	-52	-46	-41	-27	-31	-27	-49	-78
Mon Plank (% change)	-2	-24	-9	-22	-4	-8	-3	-7	-8	-5	-2	-9	-3
Average 3 GCMs (% change)	-26	-33	-28	-37	-32	-25	-16	-17	-11	-15	-17	-26	-42

Table A5.10 Temora site-Baseline ewe supplementary intake (average) and the variance (percent change) for the three GCMs

Climate Scenario	Intake (kg/head/year)		
	Total supp	Total Pasture	Total
Baseline (kg/hd/year)	62.2	415.5	477.7
CCSM (% change)	23	-8	-4
Hadley (% change)	64	-26	-14
Mon Plank (% change)	6	-2	-1
Average 3 GCMs (% change)	31	-12	-6

Condobolin

Table A5.11 Condobolin site-Baseline harvest date (average) for each crop and the variance (percent change) for the three GCMs

Climate Scenario	Crop	
	Barley	Wheat
Baseline	16 Oct	08 Nov
CCSM (% change)	-5	-2
Hadley (% change)	-5	-3
Mon Plank (% change)	-5	-3
Average 3 GCMs (% change)	-5	-3

TableA 5.12 Condobolin site-Baseline gross margins (average) for each system and the variance (percent change) for the three GCMs

Climate Scenario	System		
	Animal	Crop	Farm
Baseline ($)	$110.15	$159.79	$141.18
CCSM (% change)	-29	-10	-16
Hadley (% change)	-44	-14	-22
Mon Plank (% change)	-23	-9	-13
Average 3 GCMs (% change)	-32	-11	-17

Table A5.13 Condobolin site-Baseline monthly total dry mater (average) and the variance (percent change) for the three GCMs

Climate Scenario	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline (kg/ha)	769	710	657	610	603	617	592	617	721	851	859	839
CCSM (% change)	-27	-32	-33	-30	-34	-33	-23	-14	-16	-17	-25	-31
Hadley (% change)	-48	-45	-41	-42	-48	-49	-41	-33	-24	-24	-30	-45
Mon Plank (% change)	-23	-18	-21	-24	-28	-28	-14	-4	-8	-8	-21	-25
Average 3 GCMs (% change)	-32	-31	-32	-32	-37	-36	-26	-17	-16	-16	-25	-34

Table A5.14 Condobolin site-Baseline monthly and overall groundcover (average) and the variance (percent change) for the three GCMs

Climate Scenario	Month												Overall (years)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Baseline (%)	80	73	73	77	82	84	89	91	95	98	93	89	64
CCSM (% change)	-38	-32	-42	-40	-44	-36	-40	-24	-19	-22	-21	-35	-81
Hadley (% change)	-52	-42	-47	-55	-63	-63	-53	-37	-31	-26	-34	-57	-77
Mon Plank (% change)	-43	-42	-42	-40	-44	-36	-27	-16	-19	-14	-34	-44	-58
Average 3 GCMs (% change)	-44	-39	-44	-45	-50	-45	-40	-25	-23	-20	-30	-45	-72

Table A5.15 Condobolin site-Baseline ewe supplementary intake (average) and the variance (percent change) for the three GCMs

Climate Scenario	Intake (kg/head/year)		
	Total supp	Total Pasture	Total
Baseline (kg/hd/yr)	55.2	409.9	465.0
CCSM (% change)	69	-23	-12
Hadley (% change)	86	-30	-16
Mon Plank (% change)	58	-20	-10
Average 3 GCMs (% change)	71	-24	-13

Appendix 6. Site statistical climate analysis

Goolgowi

Annual Summary

Variables	Baseline	Impact % variance on baseline CCSM	Hadley	Mon Plank	Average GCM's
Average Rainfall mm	380	8	-11	14	3
Annual average temperature (max) °C	23.8	6	6	4	5
Annual average temperature (min) °C	10.2	10	14	11	12
Absolute maximum temperature °C	42.0	7	8	7	7
Absolute minimum temperature °C	-2.4	-33	-25	-33	-30

Mean Rainfall (mm)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Current (1957-2012)	31.9	27.96	34.74	26.63	33.09	29.28	31.41	34.39	32.08	36.39	30.19	29.88
CCSM (2030)	23.42	39.44	44.75	32.43	31.27	28.87	22.88	32.36	29.09	33.35	52.59	33.17
change (%)	-26.6	41.1	28.8	21.8	-5.5	-1.4	-27.2	-5.9	-9.3	-8.4	74.2	11
Hadley (2030)	34.43	23.15	26.61	22.17	36.32	28.46	44.57	27.7	35.16	23.64	14.59	20.64
change (%)	7.9	-17.2	-23.4	-16.7	9.8	-2.8	41.9	-19.5	9.6	-35	-51.7	-30.9
Mon Plank (2030)	34.31	30.38	40.08	34.78	53.58	25.7	26.29	36.86	42.61	36.8	36.93	38
change (%)	7.6	8.7	15.4	30.6	61.9	-12.2	-16.3	7.2	32.8	1.1	22.3	27.2

Mean Temperature (C)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Current (1957-2012)	25.25	24.89	21.61	17.09	12.94	10.04	8.99	10.49	13.24	16.84	20.47	23.13
CCSM (2030)	25.98	26.57	22.24	18.76	13.87	11.3	10.11	11.62	14.31	17.89	21.78	24.19
change (%)	2.9	6.7	2.9	9.8	7.2	12.5	12.5	10.8	8.1	6.2	6.4	4.6
Hadley (2030)	26.1	26.88	23.38	18.97	13.98	10.75	10.24	11.36	14.68	18.78	21.94	25.26
change (%)	3.4	8	8.2	11	8	7.1	13.9	8.3	10.9	11.5	7.2	9.2
Mon Plank (2030)	26.31	25.58	22.46	18.65	14.11	11	10.04	11.53	13.86	17.86	21.87	24.74
change (%)	4.2	2.8	3.9	9.1	9	9.6	11.7	9.9	4.7	6.1	6.8	7

Extreme Events: Percent of time exceeding (1957-2012) the 99th percentile of maximum temperatures recorded within the month

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Temperature Threshold (99th Percentile)	45.5	45	41.47	35.93	29	25	25.79	29.97	35.46	38.93	42.5	43.97
Current (1957-2012)	0	0	0.06	0.06	0	0	0.06	0.06	0.06	0.06	0	0.06
CCSM (2030)	0.32	1.06	0.54	2.56	0.75	0.11	0	0.11	0	0.32	0.89	0.32
change %	0.32	1.06	0.48	2.5	0.75	0.11	-0.06	0.05	-0.06	0.26	0.89	0.26
Hadley (2030)	1.08	0.94	0.54	1	0.86	0.22	0	0	0	0.43	0.89	1.08
change %	1.08	0.94	0.48	0.94	0.86	0.22	-0.06	-0.06	-0.06	0.37	0.89	1.02
Mon Plank (2030)	2.37	0	0.54	0.78	0.75	0.89	0	0	0	0.54	0.67	1.29
change %	2.37	0	0.48	0.72	0.75	0.89	-0.06	-0.06	-0.06	0.48	0.67	1.23

Percent of time in frost (< 0 C)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Current (1957-2012)	0	0	0	0	2.55	11.11	17.83	10.64	1.7	0	0	0
CCSM (2030)	0	0	0	0.44	2.8	5.22	11.94	6.56	2.22	0.65	0	0
change %	0	0	0	0.44	0.25	-5.89	-5.89	-4.08	0.52	0.65	0	0
Hadley (2030)	0	0	0	0.44	2.37	6.11	7.31	4.95	1.78	0.11	0	0
change %	0	0	0	0.44	-0.18	-5	-10.52	-5.69	0.08	0.11	0	0
Mon Plank (2030)	0	0	0	0.11	2.47	7	9.46	4.95	3	0.65	0	0
change %	0	0	0	0.11	-0.08	-4.11	-8.37	-5.69	1.3	0.65	0	0

Temora

Annual Summary

Variables	Baseline	Impact % variance on baseline			
		CCSM	Hadley	Mon Plank	Average GCM's
Average Rainfall mm	482	8	-11	6	1
Annual average temperature (max) °C	23.0	6	7	5	6
Annual average temperature (min) °C	9.5	10	15	13	13
Absolute maximum temperature °C	41.3	6	8	7	7
Absolute minimum temperature °C	-2.9	-34	-24	-59	-39

Mean Rainfall (mm)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Current (1957-2012)	39.68	37.93	36.7	34.5	39.75	36.35	44.42	41.32	41.45	46.52	40.31	41.44
CCSM (2030)	31.84	56.61	41.75	39.51	38.63	37.55	33.32	41.76	37.88	42.24	69.13	47.53
change (%)	-19.8	49.2	13.8	14.5	-2.8	3.3	-25	1.1	-8.6	-9.2	71.5	14.7
Hadley (2030)	41.78	30.89	30.6	22.05	47.88	31.68	57.67	35.58	50.15	36.86	21.98	27.58
change (%)	5.3	-18.6	-16.6	-36.1	20.5	-12.8	29.8	-13.9	21	-20.8	-45.5	-33.4
Mon Plank (2030)	42.92	37.05	46.68	37.24	53.31	35.87	35.23	44.01	53.76	49.46	38.42	44.47
change (%)	8.2	-2.3	27.2	7.9	34.1	-1.3	-20.7	6.5	29.7	6.3	-4.7	7.3

Mean Temperature (C)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Current (1957-2012)	24.69	24.29	21.1	16.49	12.16	9.23	8.15	9.53	12.1	15.72	19.51	22.41
CCSM (2030)	25.48	25.87	21.87	18.16	13.03	10.51	9.18	10.63	13.17	16.65	20.64	23.4
change (%)	3.2	6.5	3.6	10.1	7.2	13.9	12.6	11.5	8.8	5.9	5.8	4.4
Hadley (2030)	25.85	26.4	22.88	18.41	13.29	9.9	9.43	10.41	13.61	17.71	21.11	24.66
change (%)	4.7	8.7	8.4	11.6	9.3	7.3	15.7	9.2	12.5	12.7	8.2	10
Mon Plank (2030)	25.65	24.9	21.99	18.08	13.4	10.26	9.15	10.58	12.74	16.81	21.01	24.13
change (%)	3.9	2.5	4.2	9.6	10.2	11.2	12.3	11	5.3	6.9	7.7	7.7

Extreme Events: Percent of time exceeding (1957-2012) the 99th percentile of maximum temperatures recorded within the month

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Temperature Threshold (99th Percentile)	44.97	43.97	39.97	35.86	27.5	24	24.72	27.97	34	36.46	42	43.43
Current (1957-2012)	0.06	0.06	0.06	0.06	0	0	0.06	0.06	0	0.06	0	0.06
CCSM (2030)	0.65	0.35	0.86	0.33	2.26	0.22	0	0.11	0	1.08	0.44	0.54
change (%)	0.59	0.29	0.8	0.27	2.26	0.22	-0.06	0.05	0	1.02	0.44	0.48
Hadley (2030)	1.29	1.06	1.29	0.44	1.94	0.44	0	0.11	0.11	0.97	1	0.75
change (%)	1.23	1	1.23	0.38	1.94	0.44	-0.06	0.05	0.11	0.91	1	0.69
Mon Plank (2030)	1.94	0	0.65	1.11	1.61	0.33	0.11	0	0.11	0.97	0.56	0.43
change (%)	1.88	-0.06	0.59	1.05	1.61	0.33	0.05	-0.06	0.11	0.91	0.56	0.37

Percent of time in frost (< 0 C)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Current (1957-2012)	0	0	0	0.18	5.49	16.67	25.41	16.92	4.85	0.28	0	0
CCSM (2030)	0	0	0	0.44	5.16	8.44	17.42	9.89	5.11	1.18	0.11	0
change (%)	0	0	0	0.26	-0.33	-8.23	-7.99	-7.03	0.26	0.9	0.11	0
Hadley (2030)	0	0	0	0.22	3.87	10.67	8.92	8.39	3.56	0.65	0	0
change (%)	0	0	0	0.04	-1.62	-6	-16.49	-8.53	-1.29	0.37	0	0
Mon Plank (2030)	0	0	0	0.33	2.9	12.67	15.16	6.99	5.89	0.65	0.11	0
change (%)	0	0	0	0.15	-2.59	-4	-10.25	-9.93	1.04	0.37	0.11	0

Condobolin

Annual summary

Variables	Baseline	Impact % variance on baseline			
		CCSM	Hadley	Mon Plank	Average GCM's
Average Rainfall mm	404	2	-13	9	-1
Annual average temperature (max) °C	24.6	6	7	4	5
Annual average temperature (min) °C	11.0	10	13	11	11
Absolute maximum temperature °C	42.5	6	9	7	7
Absolute minimum temperature °C	-2.0	-45	-30	-30	-35

Mean Rainfall (mm)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Current (1957-2012)	38.66	33.16	35.24	25.73	31.89	33.17	35.24	29.7	29.92	37.24	35.1	38.19
CCSM (2030)	29.56	42	33.14	24.72	29.6	32.19	23.4	33.84	26.26	42	50.16	44.16
change (%)	-23.5	26.7	-6	-3.9	-7.2	-3	-33.6	13.9	-12.2	12.8	42.9	15.6
Hadley (2030)	41.38	27.07	29.27	15.56	36.29	24.97	46.39	25.9	32.14	28.95	17.54	25.66
change (%)	7	-18.4	-16.9	-39.5	13.8	-24.7	31.6	-12.8	7.4	-22.3	-50	-32.8
Mon Plank (2030)	44.76	31.21	41	25.17	44.84	30.89	26.91	34.15	43.61	44.26	37.84	45.91
change (%)	15.8	-5.9	16.3	-2.2	40.6	-6.9	-23.6	15	45.8	18.9	7.8	20.2

Mean Temperature (C)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Current (1957-2012)	26.28	25.76	22.56	17.92	13.46	10.43	9.4	10.94	13.99	17.82	21.49	24.28
CCSM (2030)	27.11	27.4	23.39	19.64	14.56	11.71	10.48	12.14	15.12	18.83	22.76	25.29
change (%)	3.2	6.4	3.7	9.6	8.2	12.3	11.5	11	8.1	5.7	5.9	4.2
Hadley (2030)	27.4	27.92	24.29	19.69	14.64	11.17	10.68	11.82	15.57	19.87	23.09	26.5
change (%)	4.3	8.4	7.7	9.9	8.8	7.1	13.6	8	11.3	11.5	7.4	9.1
Mon Plank (2030)	27.02	26.41	23.34	19.41	14.67	11.52	10.54	12.12	14.69	18.97	22.94	25.75
change (%)	2.8	2.5	3.5	8.3	9	10.5	12.1	10.8	5	6.5	6.7	6.1

Extreme Events: Percent of time exceeding (1957-2012) the 99th percentile of maximum temperatures recorded within the month

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Temperature Threshold (99th Percentile)	46.47	45.9	41.43	36.82	28.97	25.96	25.86	30.4	36	38.5	44.43	43.5
Current (1957-2012)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0	0	0.06	0
CCSM (2030)	0.86	0.94	0.11	0.33	1.72	0.11	0	0	0.11	0.97	0	0.54
change (%)	0.8	0.88	0.05	0.27	1.66	0.05	-0.06	-0.06	0.11	0.97	-0.06	0.54
Hadley (2030)	0.86	1.06	1.51	1	1.72	0	0	0	0.22	1.61	0.67	1.61
change (%)	0.8	1	1.45	0.94	1.66	-0.06	-0.06	-0.06	0.22	1.61	0.61	1.61
Mon Plank (2030)	0.97	0.24	0.22	0.22	2.15	0.22	0	0	0.11	1.18	0.33	1.83
change (%)	0.91	0.18	0.16	0.16	2.09	0.16	-0.06	-0.06	0.11	1.18	0.27	1.83

Percent of time in frost (< 0 C)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Current (1957-2012)	0	0	0	0	1.13	8.07	15.05	7.3	0.82	0	0	0
CCSM (2030)	0	0	0	0	2.04	3.89	10.11	5.27	1.89	0	0	0
change (%)	0	0	0	0	0.91	-4.18	-4.94	-2.03	1.07	0	0	0
Hadley (2030)	0	0	0	0	1.94	5.22	5.91	5.38	0.78	0.11	0	0
change (%)	0	0	0	0	0.81	-2.85	-9.14	-1.92	-0.04	0.11	0	0
Mon Plank (2030)	0	0	0	0	1.61	5.56	6.13	3.23	1	0.32	0	0
change (%)	0	0	0	0	0.48	-2.51	-8.92	-4.07	0.18	0.32	0	0

Appendix 7. Summary of site adaptation response.

Site	Adaptation option	Variables analysed	CCSM	Hadley	Mon Plank
Goolgowi	**Not sow crop**	*Gross Margin for farm*	Increase average GM + decrease in probability of lower returns	Increase average GM + decrease in probability of lower returns	Slight improvement in average GM decrease in probability of lower returns.
		Gross Margin for crop	Small change in average GM, decrease in probability of lower returns..	Tightening of GM probabilities at both top and bottom end.	Slight decrease in GM probability.
		Crop Yield	Across species a tightening of yield probabilities.	Across species an increase in average yield and a tightening of yield probabilities.	Across species and increase in average yields and a tightening of yield probabilities.
		% Years don't sow	Increase in the number of years that barley and wheat were not sown. 23% chance that the final crop rotation was not sown.	Increase in the number of years that barley and wheat were not sown. 19% chance that the final crop rotation was not sown.	Increase in the number of years that barley and wheat were not sown. 8% chance that the final crop rotation was not sown.
	Improved genetics	*Gross Margin farm*	Slight increase in average GM small improvement overall GM probability	Slight increase in average GM small improvement overall GM probability	Slight increase in average GM small improvement overall GM probability
		Gross Margin for animal	Increase in average GM and decrease in probabilities of lower returns	Increase in average GM and small improvements in GM probabilities	Increase in average GM and improvements in GM probabilities
		Lamb performance	Improvements in median lamb weight	Improvements in median lamb weight	Improvements in median lamb weight
		Average days to lamb turn off	Reduction in number of days to reach sale weight	Reduction in number of days to reach sale weight	Reduction in number of days to reach sale weight
	Lowering ground cover thresholds	*Gross Margin farm*	No change in average GM, slight decrease in probability of lower return.	No change in average GM slight decrease in probabilities of lower returns	No change
		Minimum ground cover farm	No change	No change	No change
		Supplementation levels to ewes	Slight decrease in the level of supplementation required through winter	Slight decrease in the level of supplementation required through winter	Slight decrease in the level of supplementation required through winter

Site	Adaptation option	Variables analysed	CCSM	Hadley	Mon Plank
Temora	**Not sow crop**	*Gross Margin for farm*	Decrease average GM return and slight increase in the probabilities of low end returns	Slight decrease in average GM return and slight increase in the probabilities of low end returns	Decrease average GM return and slight increase in the probabilities of low end returns
		Gross Margin for crop	Decrease average GM return and increase in probabilities of more varied returns.	Decrease average GM return and increase in probabilities of more varied returns	Slight decrease average GM return increase in probabilities of more varied returns.
		Crop Yield	Decrease in average barley yields and increases in canola and wheat	Increase in average Barley and wheat yield and slight decrease in canola	Increase in average across all species
		% Years don't sow	Increase in the number of years that canola and wheat were not sown. 31% chance that the final crop rotation was not sown.	Increase in the number of years that canola and wheat were not sown. 23% chance that the final crop rotation was not sown.	Increase in the number of years that canola and wheat were not sown. 19% chance that the final crop rotation was not sown.
	Improved genetics	*Gross Margin farm*	Slight improvement in average GM return. Slight positive upward shift in GM probabilities	Slight improvement in average GM return. Slight positive upward shift in GM probabilities	Slight improvement in average GM return. Slight positive upward shift in GM probabilities
		Gross Margin for animal	Improvement in average GM return. Slight positive upward shift in GM probabilities	Improvement in average GM return.	Improvement in average GM return. Positive upward shift in GM probabilities
		Lamb performance	Improvements in median lamb weight	Improvements in median lamb weight	Improvements in median lamb weight
		Average days to lamb turn off	Reduction in number of days to reach sale weight	Reduction in number of days to reach sale weight	Reduction in number of days to reach sale weight
	Lowering ground cover thresholds	*Gross Margin farm*	No change in average GM's	Slight improvement in average GM return	Slight decrease in average GM return
		Minimum ground cover farm	No change	No change	No change
		Supplementation levels to ewes	Slight decrease	Slight decrease	Slight increase

Site	Adaptation option	Variables analysed	CCSM	Hadley	Mon Plank
Condobolin	**Not sow crop**	*Gross Margin for farm*	Slight increase in average GM return and decrease in probabilities of lower end returns.	Slight increase in average GM return and decrease in probability of lower end returns	Slight increase in average GM return and decrease in probabilities of lower end returns
		Gross Margin for crop	No change in GM return but decrease in probability of lower returns	Slight increase in GM return but decrease in probability of lower returns	Slight decrease in GM and decrease in probability of high end returns.
		Crop Yield	Slight increase in average yield, no change in yield distribution	Slight increase in average yield, improvement in upper end yield distribution	Slight increase in average yield, no change in yield distribution
		% Years don't sow	Slight increase in %years crops were not sown.	Slight increase in % years crops were not sown.	Minor change to number of years crops were not sown.
	Improved genetics	*Gross Margin farm*	Slightly improved average GM	Slightly improved average GM	No change to the average GM
		Gross Margin for animal	Slightly improved the average GM and decrease in the probability of low end returns.	Slightly improved the average GM and higher probability high end returns.	No change to the average and decreased probabilities of low end returns.
		Lamb performance	Improvements in median lamb weight	Improvements in median lamb weight	Improvements in median lamb weight
		Average days to lamb turn off	Reduction in number of days to reach sale weight	Reduction in number of days to reach sale weight	Reduction in number of days to reach sale weight
	Lowering ground cover thresholds	*Gross Margin farm*	No change to average GM	No change to average GM	No change to average GM
		Minimum ground cover farm	Slight increase in seasonal pasture cover during Autumn only	No change to seasonal pasture cover evident	No change to seasonal pasture cover evident
		Supplementation levels to ewes	No change to median supplementation intake	Slight increase and change in supplementation demand in late Autumn and early Winter	No change to median supplementation intake