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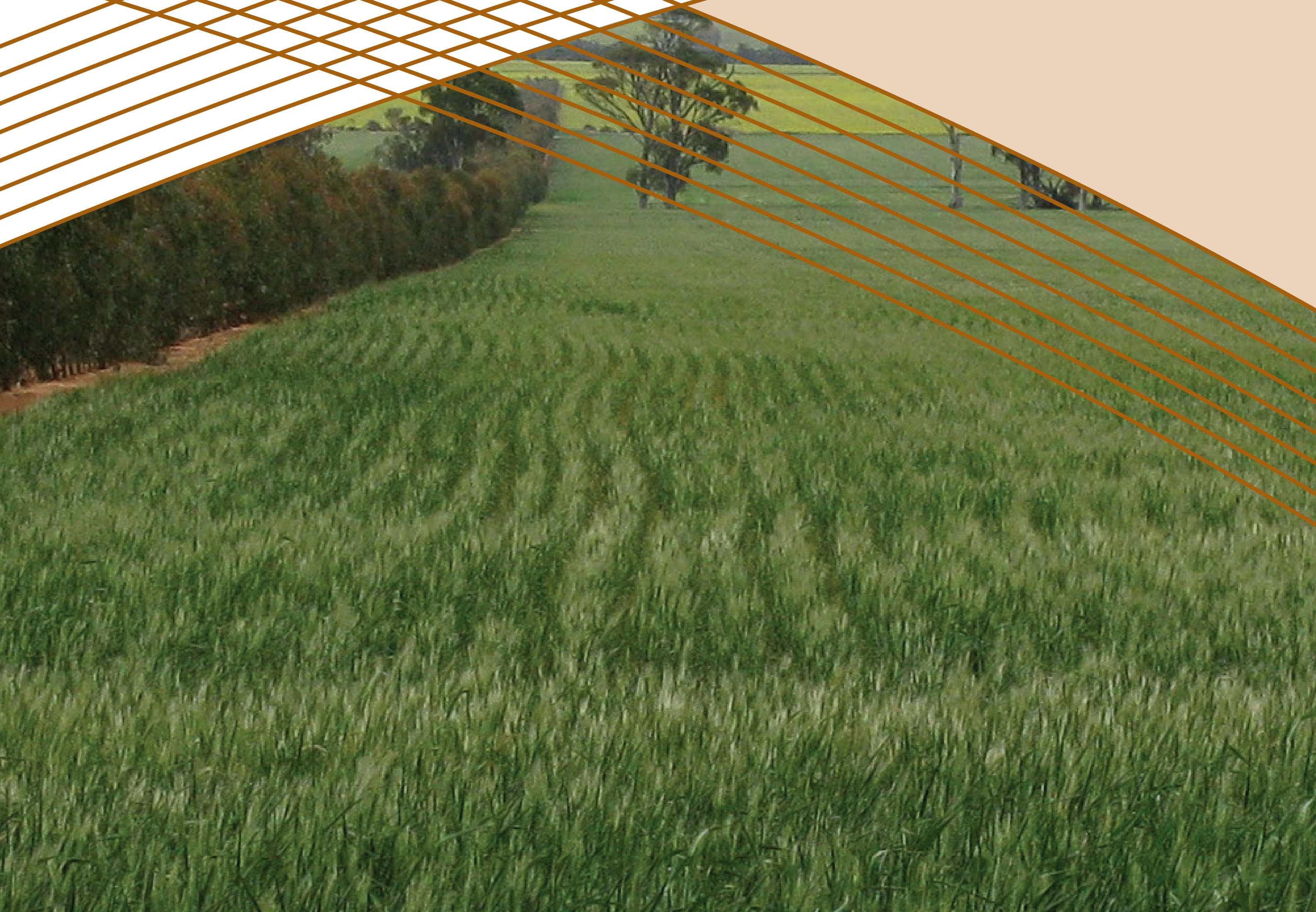
Everfarm® – Climate adapted perennial-based farming systems for dryland agriculture in Southern Australia

Final Report

Robert Farquharson, Amir Abadi, John Finlayson, Thiagarajah Ramilan, De Li Lui, Muhuddin Anwar, Steve Clark, Susan Robertson, Daniel Mendham, Quenten Thomas and John McGrath



EverFarm® – Climate adapted perennial-based farming systems for dryland agriculture in southern Australia

Robert Farquharson[1], Amir Abadi [2], John Finlayson[3], Thiagarajah Ramilan[1], De Li Liu[4], Anwar Muhaddin[4], Steve Clark[5], Susan Robertson[6], Daniel Mendham[7], Quenten Thomas[8] and John McGrath[9]

[1] Future Farm Industries Cooperative Research Centre and University of Melbourne

[2] Future Farm Industries Cooperative Research Centre and Western Australian Department of Environment and Conservation

[3] Future Farm Industries Cooperative Research Centre and University of Western Australia

[4] New South Wales Department of Primary Industries

[5] Victorian Department of Primary Industries

[6] Charles Sturt University

[7] Future Farm Industries Cooperative Research Centre and CSIRO Ecosystem Sciences

[8] Quisitive Pty Ltd

[9] Future Farm Industries Cooperative Research Centre

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The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

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Figure 8.1. P1 Mallee Harvester, permission received courtesy of Future Farm Industries Cooperative Research Centre (FFICRC).

Table of Contents

List of figures

List of tables

ABSTRACT

Australian dryland agriculture will be affected by climate change in a number of ways. First, higher temperatures and changes to rainfall are likely to create greater variability of crop yields and livestock productivity. Second, government policies introduced to mitigate greenhouse gas emissions are likely to influence production costs and commodity prices. Third, global trade patterns are likely to alter as populations increase, and as climate change continues to affect producers and consumers worldwide. This will create both challenges and opportunities for Australian agriculture.

Farmers will have to respond to the additional challenge of climate change even when it is compounded by existing long term stresses associated with declining terms of trade, climate variability and existing environmental issues. Investing in new land-use options to combat climate change, with their associated risks, is made more difficult by being set against a backdrop of declining profitability.

The opportunity to create transformational change in farming enterprises was tested by combining the multiple components of the potential future perennial- based dryland farming systems and assessing their expected contribution to climate change adaptation. This project has found that adopting perennial pastures for livestock grazing and tree crops for biomass production, when planted on appropriate soils, can improve profitability when compared to the existing land uses facing a changing climate. In some farming systems increased cropping is likely to result in improved future farm profits.

This work demonstrated that mallees as a biomass tree crop can be cohesively integrated into existing farming systems with minimal interruption to normal operations of livestock and cropping enterprises. A woody biomass crop can be profitable and diversify revenue risk by enabling farmers to supply biomass and sequester carbon to relevant markets. This work demonstrates suitable designs of a mallee belt planting layout that minimizes costs and maximizes benefits when planted in appropriate agro- climatic zones and where there are adequate soil conditions. Knowledge developed from this work will help build farmers capacity about climate change adaptation and assist in achieving positive social, environmental and economic outcomes.

EXECUTIVE SUMMARY

This multi-disciplinary farm economic analysis has assessed new perennial pastures and mallee trees for biomass as adaptation options for dryland farming systems in southern Australia.

A small survey was conducted of farmers/graziers, agricultural consultants, and agricultural researchers at the commencement of the project. The objectives were to find out about existing farming systems in each project location, to ascertain the opinion of respondents about predicted climate change and find out how they might react to it, and to canvass their responses to a potential on-farm tree activity - growing mallees for biomass in production of renewable fuel and energy. The farmers showed that their management is attuned, and responsive, to environmental variability and changes in their circumstances that occur over time. This is exhibited in their strategic and tactical management responses.

With respect to predicted climate change these farmers were generally confident that they could adapt (at least in the short term) to changes in the distribution of temperature and rainfall. Given their knowledge and experience, they were looking for new technologies (sometimes expressed as plant varietal improvements and other technologies) to help them in the adaptation process. In managing their farm businesses, they are used to reacting to chance and change in climate.

In terms of their personal objectives, although they were interested in environmental outcomes their main motivation was economic. This was confirmed when asked about mallee trees as a biofuels crop grown in alley farming systems. ‘Show me the money’ was an underlying response to this possibility – they were not averse to a new farming activity or concept, despite the lack of an existing market or infrastructure for farm grown woody biomass. They were willing to be innovative and adapt to taking on new opportunities and change the way they do things in response to a changed environment.

A review of recent Australian literature was used to set the scene for this project. In congruity with the research direction alluded to in the literature, the project undertook a farming systems approach using a multi-disciplinary analysis of new agricultural adaption options for a changed climate. It built on an existing biophysical research base at Future Farm Industries Cooperative Research Centre for perennial pastures and mallee for tree biomass. This enabled an economic assessment of the incentives to adapt to changes in climate.

Climate time series data for daily minimum and maximum temperature and monthly rainfall were compared for the historical record (over the years 1971 to 2011) against predictions using 18 Global Climate Models for the years 2012 to 2052. Data from this predictive modelling were downscaled to the four project locations and corrected for biases. The climate series data were then examined graphically and analyzed using statistical tests.

There was a consistent story from the information presented. Daily minimum and maximum temperatures were predicted to be higher in the future, but the situation is less clear for rainfall. Although, visually, the future distributions seem to indicate lower future rainfall, statistical tests for the rainfall series indicated less evidence for change.

Another feature of this analysis is that there was stronger statistical evidence for changes in the means of distributions than in the variances of the distributions. The non-parametric tests were not able to provide information indicating significant change in variability. It might be expected that both the central tendency and variance of selected climate series would change. There is little evidence of the latter in the results presented here. Whether this is due to a weakness in the statistical tests or is an artifact of the climate downscaling process is out of the scope of this study and a likely starting point to future research in this field.

Distributions of yields and production, resulting from biophysical modelling of responses of crops, pastures, livestock and mallee trees, for the historical and future climate series, were assessed over 40 years of historic and 40 years of a future climate scenario. The future climate scenario used for simulating and estimating production of farm enterprise was estimated with the CSIRO3.5-S2 Global Climate Model under the A2 policy scenario.

Pasture predictions were generated on a daily basis over each period as 40-year daily averages of pasture production. These numbers were aggregated over the months because we were interested in the seasonal pattern of pasture supply, which is matched against the seasonal livestock demands in the whole-farm economic model. The tree biomass growth predictions were generated by a newly developed bio-physical model which incorporates growth and regrowth patterns after coppicing every four years.

Generally the crop yield distributions were lower under a future climate. In some cases there was increased variability in the predicted yield distributions and in others there was reduced downside risk. Such results have potentially significant implications for regional farm management. The results for pasture growth need to be more carefully considered and checked. For some locations and soil types predicted future pasture production is lower than in the past, while in a smaller number of cases there are indications that the future is not so dire. The pasture results depend on the rainfall and temperature distributions, and some potential increases in pasture were explained by changes in seasonal rainfall patterns.

At Cunderdin the pasture production trends were for lower productivity over the whole year in the future compared to the historical case. At Katanning there was some indication of improved future production, more so for perennial than annual pastures. At Wagga Wagga pasture production was predicted to be substantially lower over the whole season for all species, with major implications for the farming system. But at Hamilton there was some indication that future perennial pasture production may be only slightly lower and there was evidence of a shift in seasonal patterns to increased winter-spring growth at the expense of the summer-autumn period. The landholders interviewed in that region alluded to this shift and were confident that they could adapt to it.

When considering the predictions of mallee biomass yield the important question is whether the predicted future biomass yields and patterns of growth are likely to be economically appealing in a farming systems context. This pre-supposes that a local industrial processing facility would be established and a price would be paid for biomass that makes the activity potentially appealing to landholders. The annual biomass yield in the future is different for each region and highly correlated to rainfall. The pattern of biomass production is for harvesting every four years after an initial harvest six years after planting.

Two bio-economic models were used to analyze the optimal land use mix of farms as well as their profitability and cash flow. The first was the whole-farm optimization model, MIDAS. The other was IMAGINE - a model designed for field or paddock-level analysis. Each model has its role in the study and complements the other.

The MIDAS analyses presented here used a representative whole-farm approach to answer the research question of profitability with and without perennial plants and mallee for biomass, in an historical and likely future climate. The IMAGINE model was used to investigate the same question at the farm paddock and enterprise level.

These models provide advantages for this analysis, but they have limitations as they necessarily require a number of assumptions. Models cannot fully represent reality of the circumstances and conditions of all properties and the style and constraints of all farm managers. The models used in this study, in general, represent the farmer's main economic objectives and key operational constraints, especially of resource availability. But some aspects of the operational environment are necessarily simplified to allow tractability. Despite their limitations and simplifications, these two farm economic analysis tools have proven extremely valuable in addressing important research questions of economic significance.

The whole-farm results presented here have shown that under a predicted warmer and drier climate future farm profits are likely to fall at Cunderdin and Hamilton without adaptation in the mix of enterprises and in the absence of adoption of perennial plant technologies. At Katanning the whole-farm results showed an increase in farm income under a future climate. This is associated with an increase in the farm area under pasture. In that region the climate is predicted to be warmer and wetter in autumn and winter so that pasture growth is slightly increased.

Mallee is also potentially profitable, depending on the development of regional industry processing and transport facilities, and a farm price and cost structure that is competitive with pasture/livestock activities as well as grain crops. For mallee, a new alley farming system is proposed which can be readily adapted into existing land uses. This integration is aimed at minimizing competition between tree belts and the crops and pastures in the adjacent alleys, and maximizes the synergies and positive externalities such as use of surface run-off water, shelter for livestock, reduction of recharge into saline water tables, and protection of paddocks from wind erosion. Farmer comments from the project locations were that such systems are potentially appealing but ultimately it is the financial viability that is the driver of their adoption and decision to make changes to their land use.

Another financial aspect of the decisions to change and adapt is cash flow. Analyses with IMAGINE showed the impact on cash flow over time associated with seasonal and climate change. The paddock-level cash flow analyses have shown that in general future climate projection is likely to result in increased variability and a reduction in profitability. Strategic adoption of suitable perennial pastures and biomass trees, when planted on appropriate soils, can lead to improved profitability when compared to the counterfactual. Perennial pastures and biomass tree crops do not necessarily reduce cash flow variability. In the case of perennial pastures their ability to provide green feed during summer and autumn at lower cost than supplementary grain feeding and the associated increase in livestock winter stocking rates results in higher profitability per hectare of pasture.

The project has identified several areas where gaps exist in research that are beyond the aegis of this project but have the potential for research of significant economic impact to agriculture in Australia.

A review of the mallee value chain and drivers of viability showed that development of a regional pyrolysis plant would require rostering of mallee harvesting in clusters of farms, each sharing a landing site for resource aggregation. For such a plant there would need to be substantial regional mallee plantings to provide the necessary operational throughput.

In light of this research project some directions for future R&D and policy are apparent. The gap in crop yields between what is generally achieved at the farm level and the plant biophysical limit is still substantial. A major R&D priority is further applied research, development and extension to reduce this yield gap. A second priority is for further research on the potential combined effects of price and yield variability on adaptation in a changed climate. That research was not possible within this project but it is an important question for adaptation. Other priorities are for further research in assessing farm drought responses and particularly the regional effects and options for livestock industry response to drought. A priority was identified for further R&D on mallee biomass industry (supply chain) development, to add to work already under way. The last priority identified was for funding for maintenance and development of the farming systems economic models used in this analysis. These models are valuable but they need to be maintained and improved to allow further research of farming system adaptation and response to a potentially changed climate.

1. Introduction

1.1 Climate change and the challenge of adaptation in dryland agriculture

Australian agriculture faces a number of major challenges. The risks posed by climate change will be exacerbated if the long-term downward trend in the farmer's terms of trade continues. The terms of trade for Australian agriculture have declined at an average annual rate of 1.8% between 1969–70 and 2009–10. In the future prices for Australian agricultural commodities may rise (Commonwealth of Australia (2012)), but the OECD outlook (OECD-FAO 2012) projects that the nominal prices of commodities are expected to trend upwards over the next 10 years while prices in real terms will remain flat or decline from current levels. Productivity growth has been a critical factor in maintaining industry profitability in recent decades. Growth in agricultural production largely depends on increases in productivity because of limitations in the availability of key inputs, particularly land and water resources (Productivity Commission (2009)).

Australian dryland agriculture is likely to be affected by climate change in a number of ways, although the effects are expected to vary regionally. First, higher temperatures and reduced rainfall are likely to reduce crop yields and livestock productivity. Increased carbon dioxide (CO_2) levels may offset some of these plant growth effects. However, climate projects vary between locations in Australia and elsewhere. Under a worst-case scenario of drier and warmer conditions alternative production methods and new technologies can be developed to adapt to the changing climate. Importantly, the effects of climate change will differ significantly between regions in terms of the direction, scope and types of changes. The impact of these changes and the value of adaptive responses will vary at the farm and regional scale. Second, government policies introduced to mitigate greenhouse gas emissions are likely to change production costs and commodity prices. Third, global trade patterns are likely to alter, as climate change continues to affect producers and consumers of agricultural commodities worldwide. These effects of climate change could place at risk the capacity of Australian agriculture to continue the long term productivity growth that has underpinned its success. However, as the future climate effects may vary regionally there may be opportunities for improved outcomes.

Australian agriculture needs to respond to climate change in addition to the existing long term stresses associated with declining terms of trade and climate variability. Investing in new options to combat climate change with their associated risks will be set against a backdrop of declining profitability. By combining the multiple components of the potential future perennial-based dryland farming systems and testing their contribution to adaptation to climate change, this project provides the opportunity to create transformational change in farming enterprises.

According to the Intergovernmental Panel on Climate Change (IPCC) (2009)) adaptation is defined as "adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation."

1.2 Research innovation

The major point of departure of this project is to apply economic optimisation modelling to test the capacity of novel perennial plants to be used by farm managers to transform whole farm systems and enable them to adapt to climate change. For the first time the dryland farming enterprises will be optimised including the woody crop component and for the limited and changing resources of rainfall, land, labour and finance. This new EverFarm® concept will be tested in four representative regions, under predicted climate change scenarios. Most previous assessments of the capacity of farming systems to adapt to predicted climate change have been based on assessing the impact on single components (enterprises) of the farm system using existing suites of plants. This transformational approach will use whole-farm optimisation modelling to select the mix of options that provide the best production outcomes, for systems based on novel perennial plants. This will extend the work of the Future Farm Industries Cooperative Research Centre (FFI CRC) in assessing the impact of perennial plants on agricultural productivity under existing conditions, which accommodate the known level of climatic variability, to assessing the productivity of novel perennial farming systems under predicted climate change.

The woody crop systems are a new production system based on species that are adapted to the more variable and harsh climatic conditions that are increasingly more challenging to current dryland farming systems. Such characteristics may provide strong advantages under the harsher conditions predicted for southern Australia in the future. The integration of woody crops into farming systems provides the opportunity to develop novel regional industries based on biomass production.

This project undertakes technical and economic analysis of new technologies at the farm level to specify the scope for adaptation to climate change and communicate it widely. The analysis will focus on integrating innovative perennial plant components (woody crops, fodder shrubs and herbaceous perennials) into transformative mixed farming systems to provide a new biological capability and management responsiveness for adaptation to changing climate, as well as creating resilient farming systems. Such analysis at the farm business level has not previously been undertaken and the knowledge of novel perennial systems and the analytical skills brought to this project will underpin the transformation necessary for dryland agriculture to adapt to climate change.

1.3 EverFarm® – Economics of climate change adaptation in agriculture with perennials

The EverFarm® Project used best-practice research outcomes from the FFI CRC farming systems (New Woody Crops, EverGraze, and EverCrop) to test a whole-farm approach to climate change adaptation for dryland agriculture in southern Australia. Combining the knowledge of farming systems with economic analysis skills provided the opportunity to test the role of new perennial plant technologies in transformational change for Australian agriculture to adapt to climate change. The delivery of this information will also be enhanced by utilising the extensive existing communication and training capacity within the FFI CRC.

1.3.1 Perennial pastures

The specific aim of the project was to evaluate whether and the extent to which dryland agriculture incorporating novel perennial plant technologies and farming systems can adapt to climate change. This was achieved by modelling the performance of the new perennial systems developed by the FFI CRC under predicted future climate scenarios for the dryland agricultural zone of southern Australia. The project assessed the economic feasibility for large scale adoption of perennial plants in dryland agricultural systems thus providing farmers and regional industries with the tools to assess the role of perennials in adapting to climate change. In doing this the project addressed the National Climate Change Adaptation Research Facility (NCCARF) Priority Research Area 2 ‘Transformational change in Australian primary industries’ as an adaptation response to climate change and specifically addresses research questions 5.1 and 5.3 (Transforming primary production) of the National Adaptation Research Plan (NARP) (Rickards *et al.* 2012).

1.3.2 Short-rotation woody crops – native coppicing mallee eucalypts

Integration of woody crops into dryland farming systems is a transformational change, introducing industries and markets that are entirely new in the relevant rural regions. The woody crop production systems that form the basis of this research use native tree species such as mallees that have evolved in a variable semi-arid climate and are highly productive in dispersed plantings that occupy only around 10% of the land. The trees can be arranged in narrow belts so that they cause minimal interruption to conventional cropping systems which will continue in the wide alleys between the belts. These trees live for over 50 years and regrow, or coppice, after periodic harvests that remove their above ground biomass. The harvested biomass can be locally processed thus supporting regional economic development through new employment opportunities and investments in capital and infrastructure. The biomass provides feedstocks for producers of bioenergy, biofuels and renewable industrial materials. The trees utilise the water and nutrients that move beyond the roots of annual crops and pastures, provide shelter benefits for livestock, and confer protection against erosion. These new crops can provide fundamental biological and economic change for agricultural regions with mixed crop and livestock enterprises and improve the resilience of conventional farming systems in the face of climate change.

Additionally the project addresses the high priority research question of ‘Changing production systems’ (4.1-4.2) identified by NCCARF in the Primary Industries NARP. The selection, development and utilisation of perennial plants for grazing and cropping systems increases the proportion of rainfall used by the system which may provide higher productivity and greater capacity to withstand dry periods. Outputs of the FFI CRC research to date on the performance of perennial plants in farming systems provide the opportunity to test the effectiveness of these systems against existing annual systems. The relative performance of these systems will be modeled under current and predicted future climate conditions.

1.4 Project design

1.4.1 Objective

The project objective was to evaluate the extent to which dryland agriculture incorporating new perennial plant technologies and farming systems can adapt to climate change by modelling currently achievable innovations and their economic feasibility for large scale adoption under predicted future climate scenarios for southern Australia. The project built on the bio-economic modelling and risk analysis capability of the FFI CRC, and its partners, to test the capacity of alternative novel perennial based farming systems to provide climate resilience to the southern Australian agricultural sector.

1.4.2 Hypotheses tested

The null hypothesis of the project was that under predicted climate change, incorporating a higher proportion of the farm into perennials results in similar profitability and is no less variable in net revenues than existing systems. The alternative hypothesis is that incorporating a higher proportion of perennials into farming systems will increase profitability and variability in farm incomes.

EverFarm® differentiated the biological and economic impacts of adapting to climate change across four key regions broadly representative of conditions across southern Australia. This recognises that there are important regional and industry balance aspects to adapting to climate change and that adaptive responses will be regionally specific. In recognition of the strong regional climatic, edaphic and infrastructure differences, the FFI CRC has calibrated its bio-economic models for regional application, and can support them with its region-specific technical data.

1.4.3 Project locations

The project was designed around four case study sites, with two sites in south-eastern Australia (Hamilton and Tarcutta/Wagga Wagga) and two in south-western Australia (Cunderdin and Katanning) (see Figure 1.1). These locations were selected as they are representative of large areas of southern Australia. The bioeconomic models and data to drive the models were available in these selected regions. The additional modelling to assess the capacity of systems that incorporate perennials to adapt to climate change relied on the use of economic models already available and calibrated for the selected regions by the FFI CRC.

Figure 1.1 Study locations

1.4.4 Effects tested

The project tested two main effects: the impact of climate change (current climate versus predicted future climate) and the effect of additional perennials in farming systems (annual-based farming system versus farming system with additional perennials). This was done by modelling four scenarios in each of the selected regions.

The four scenarios evaluated in each region to test the impact of novel perennials on the adaptive capacity of agricultural systems were:

- Scenario 1: Current (historical) climate and annual farming systems (status quo for base climatic conditions);
- Scenario 2: Current (historical) climate and perennial-based farming systems (perennial farming systems for base climatic conditions);
- Scenario 3: Predicted climate and annual farming systems (new climate and annual farming system); and
- Scenario 4: Predicted climate and perennial based farming systems (new farming system and new climate).

The scenarios used to test the effects of climate change adaptation with perenniality are shown in Table 1.1. Analyses of 'historic' and '2030 dry' climate scenarios do not imply that these are snapshots of climate at any point in time. Rather, the scenarios were analysed using 40-year climate records as input to plant simulation models. Hence the scenarios are not assumed to be static situations, but the change in climate over both periods is captured by the use of these climate data series in the analysis.

Table 1.1 Scenarios tested

Assessed in *current year terms*	**Perennial plants, shrubs and trees**	
	Without	With
Historic Climate	X	X
A 2030 Dry Climate	X	X

1.5 Economic models

The FFI CRC has access to whole-farm and paddock-level bio-economic models (including MIDAS and IMAGINE) to examine the impact of changes in farming systems on farm profitability. Flugge and Abadi (2006) show an example of the use of MIDAS for economic evaluation of the place of an innovation in a farming system. Bartle and Abadi (2010) provide a case study of the use of IMAGINE for assessing the commercial viability of energy tree crops in a WA farming system. These models will use the outputs from plant growth models like APSIM and GrassGro, which simulate growth and yield of annual and perennial crops and pastures from agro-climatic and physiological parameters.

The inputs to the economic models (system productivity) were estimated using outputs from plant growth models based on alternative climate scenarios. The bio-economic models were used to assess land use sequences under variable conditions and evaluate the profitability of alternative farming systems under different climatic scenarios.

1.5.1 Modeling analyses

To assess these scenarios the analyses included several components (Figure 1.2).

First was preparation of technical (biological) specifications for the novel perennial plant technologies in each regional setting, and prediction of the productivity for the integrated systems to be used in the economic analyses for each climate scenario. The productivity predictions were based on climate data downscaled from Global Climate Models (GCMs).

Second was economic analysis to simulate and optimise the performance of farms that utilize the new perennial and existing annual crop/pasture components. It also included an assessment of risk associated with each farming system.

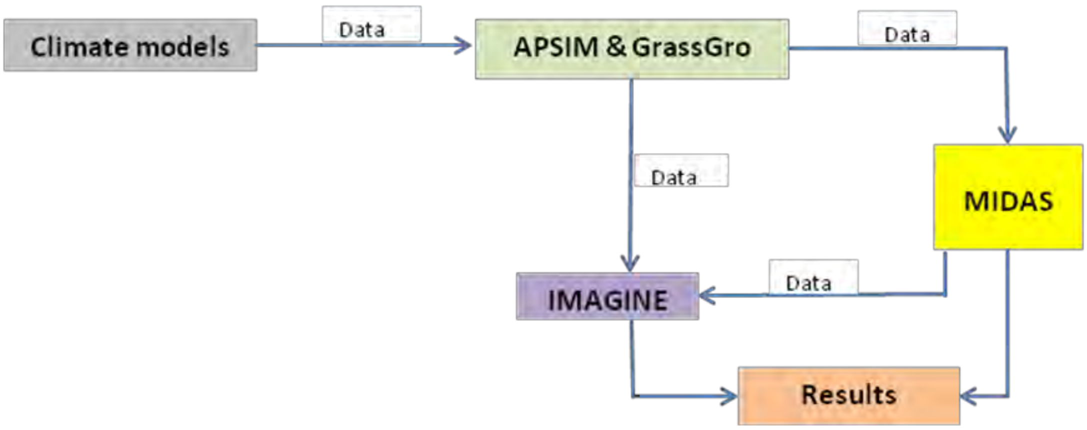


Figure 1.2 Modelling and analysis used

2. Profitability of perennial-based farming systems in a changed farming climate

Summary

Results of economic analyses presented in this chapter indicate that future climate projection is likely to have negative impacts in some regions and positive impacts in others. Either way perennials investigated in this project result in improvement in farm profitability when adopted on appropriate soils according to recommended design principles.

The projected shift in the distribution of the growing season rainfall in the four regions that we studied is economically significant. In water limited regions, such as the central wheatbelt of WA, increased frequency of warmer and drier winters and springs will result in reduced yields leading to lower mean net enterprise returns (gross margins) for crops and livestock. In regions, such as Katanning in WA or Hamilton in Victoria, where winter and springs are cold and rainfall can in some years exceed the water requirements of plant, slightly higher temperatures, small reductions in rainfall and higher CO_2, is likely to enhance productivity of grain and livestock systems, improving their profitability.

The whole-farm results presented here have shown that under a predicted warmer and drier climate future farm profits are likely to fall at Cunderdin and Hamilton without farm management adaptation. At Katanning the whole-farm results showed an increase in farm income under a future climate. This is associated with an increase in the farm area under pasture. In that region the climate is predicted to be warmer and wetter in autumn and winter (Chapter 5) so that pasture growth is slightly increased (Chapter 6).

The perennial pasture and biomass tree adaptation options are predicted to have a positive effect on whole-farm profit at each of these locations and the associated changes for particular soil types (LMUs) give a deeper understanding of the farming systems changes associated with these adaptations.

The optimizing models used for this analysis provide a yet richer understanding of the impetus for change through provision of the marginal value product (MVP) of farm enterprises under each scenario. The MVP information indicates the economic motivation for these management changes.

The paddock-level cash flow analyses have shown that in general future climate projection is likely to result in increased variability and slight reduction in profitability. Strategic adoption of suitable perennial pastures and biomass trees, when planted on appropriate soils, can lead to improved profitability when compared to the counterfactual. Perennial pastures and biomass tree crops do not necessarily reduce cash flow variability. In the case of perennial pastures their ability to provide green feed during summer and autumn at lower cost than supplementary grain feeding and the associated increase in livestock winter stocking rates results in higher profitability per hectare of pasture.

At Wagga Wagga the paddock-level analyses for particular enterprises and soils showed that expected future profit as expressed by the annual equivalent value of net returns (AEVs) generally declined under a changed climate without adaptation, and even with adaptation the

climate effects were still likely to be detrimental to cash flows. There is substantial increase in income variability at Wagga Wagga under a changed climate.

Trees show smaller variability in their biomass growth compared to agricultural crops and pastures. Where a market for whole-tree biomass develops, these trees can provide an opportunity for diversification of farm income. Stable supply and demand for farm-grown coppice tree biomass is likely to be based on secure forward contracts. The price of biomass is strongly linked to the movements of the energy market and demand for renewable energy and fuel. The price received by the growers for biomass must compensate them for the cost of planting, replacement of nutrients exported with biomass, profit forgone on the land occupied by the trees and the value of reduced profits in the narrow zone of competition between trees and adjacent agricultural crops and pastures.

The optimal planting design, from agronomic and hydrological points of view, is for trees to be planted in two-row belts with wide (100 m) alleys of agriculture. This means that only about 6% of a paddock will be occupied by the trees. This modest land occupation will make a commensurate and positive contribution to the profitability of the paddocks they occupy. Their coppice harvest once every 4 years provides an injection of income from the sale of biomass increasing the peaks of cash flow without exacerbation the troughs or down side.

2.1 Introduction

In this chapter we present the economic results of the project. The purpose of this project is to combine rigour with relevance in generating useful insights for decision makers concerned with climate change and agriculture. We acknowledge interested entities may be land holders, farm advisors, private firms and public agencies interested in R&D funding or climate change policies for agriculture. As such these results are presented so as to provide general information about farm-level and policy decisions.

Since the farm financial implications of perenniality and climate change are of primary interest to the project, we present the main economic results first. The data and inputs developed and used as inputs in these analyses are given in subsequent chapters.

The modelling processes were shown schematically in Figure 1.2. The comparisons are of farming systems at each location for historical and future climates with and without perennial plants and mallee trees for biomass.

The farm financial analyses have been conducted in a farming systems context, because farmers and their advisors must make decisions by considering the whole farming system (and our interviews with farmers and consultants at each location (Chapter 4) confirmed this imperative). However, farmers are constrained in many ways in the management choices that are available to them. Our paddock scale results are presented in recognition of the fact that subsequent to farm manager deciding on the land use strategies at the whole of farm scale (e.g. proportion of farm to allocate to crops and pasture) they must decide how to manage each paddock to optimize its agronomic and cash flow potential.

We used a representative farm approach to develop information about the likely responses to these perenniality options for the above decision makers (Chapter 3). Two types of economic analyses have been conducted.

First, a whole-farm economic analysis was conducted which focuses on the farming system responses to the research question, including likely impacts on farm profits and farm enterprise mix. These analyses use farming systems models which have a profit objective while incorporating the important constraints that farm managers must consider. These are linear programming models (Pannell 1997) – the MIDAS model framework, used by Kingwell and Pannell (1987), Finlayson et al. (2012a), Finlayson et al. (2012b), was adapted to each location for this part of the analysis.

This approach has the strength of focusing on the farm profit objective while incorporating the typical management restrictions including different soil types and productivity, prevailing and forecast seasonal patterns (including seasonality), and crop sequence imperatives.

However, the approach focuses solely on farm profit as an objective, adopting an average 'year in – year out' approach which does not account for variability in operating environment from year to year (e.g. climatic effects on plant and animal responses).

Therefore the second analysis, using IMAGINE, a paddock-level simulation model, utilizes the findings of whole-farm analysis - Abadi and Cooper (2004), Mendham et al. (2012). Analysis with IMAGINE enables consideration of stochastic and temporal interactions to develop cash flows over time and financial measures for comparison. Long-term cash flows were annualized into AEV numbers ($/ha) to compare cash flow patterns over equivalent time periods.

The MIDAS analysis was conducted for Cunderdin, Katanning and Hamilton, and the IMAGINE analysis for Cunderdin, Katanning, Wagga Wagga and Hamilton. Further explanation of the MIDAS and IMAGINE models is presented in Chapter 7.

In this analysis the investigation of climate change effects is undertaken by using outputs from one future climate, based on predictions from the CSIRO-Mk 3.5 (S2) model under A2 policy scenario where CO2 level stabilizes at 550 ppm (see Chapter 5), compared to an historical sequence. The future (S2) climate effects are estimated over the 40-year period 2012 – 2052 compared to the effects over the historical period of 1971-2011.

The full MIDAS results for each location are presented in Appendix A. In this chapter the highlights of those, and the IMAGINE results, are presented.

2.2 Economics of farm-level adaptation

2.2.1 Results for Cunderdin

2.2.1.1 Whole-farm results

The whole-farm results for Cunderdin are shown in Table 2.1. In the base case (crops and annual pasture) the effect of a changed future climate is to reduce whole-farm income by about 20%. As perennials were added in both climate types farm income increased and as mallee was further added farm profit increased slightly more. Under a changed future climate the addition of perennials and mallee increased farm income back above the historical base level.

Table 2.1 MIDAS whole-farm results: profit and land use: Cunderdin

	Percentage of farm area (%)					Farm Profit
	Crop	Annual pasture	Perennial pasture		Mallee	
			Lucerne	Tedera		$/ha
Historical climate						
Base	83	17	-	-	-	110
With PP	50	24	4	21	-	129
With PP & Mallee	49	28	4	17	1	131
Future climate						
Base (no PP)	83	17	-	-	-	89
With PP	49	18	27	6	-	113
With PP & Mallee	46	18	28	7	2	116

The proportion of farm area in crop and annual pasture was 83:17 in the base case, and this was unchanged in the future climate scenario. This land use mix accords with typical farms in the Central Wheat Belt of Western Australia (Planfarm-Bankwest 2012). When perennial pastures and mallees were introduced they accounted for 22% of farm area in the historical climate and 37% in the future climate. The proportion of farm area in mallee was 1-2%: due to the particular layout of mallee in an alley system the maximum possible farm area for mallee is only 6%.

The LMU areas, optimal rotations and MVPs for the future climate with perennial pastures and mallee are in Table 2.2. As expected, the poorer soils (LMUs 1, 2, 4 and 7) have the lowest MVPs. Lucerne is used in rotations on LMUs 5, 7 and 8. Tedera is in a rotation on LMU 8. Mallee is adopted on LMUs 1, 2 and 8. This information provides a detailed prediction of on-farm incentive to change to these new species when soil types and the alternative economic uses of LMUs are considered in a farming system context.

Table 2.2 MVPs (profit contributions) of land use on LMUs: with perennial pastures & mallee: future climate: Cunderdin

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected (area allocated)
1	140	57	Continuous pasture and mallee
2	210	134	Continuous pasture and mallee
3	350	257	Wheat, canola, wheat, lupin
4	210	182	3 yr lucerne, wheat, barley
5	200	246	3 yr lucerne, wheat, barley, continuous pasture
6	200	237	Wheat, canola, barley, field pea
7	300	175	3 yr lucerne, wheat, barley
8	390	229	4 yr lucerne, wheat, canola, barley, lupin, wheat, 4 yr lucerne, wheat and mallee, tedera

2.2.1.2 Paddock-level results

Paddock-level results for Cunderdin are presented for deep sands (pasture) and deep sandy duplex soils (crops).

2.2.1.2.1 Cropping results

Figure 2.1 shows cash flows for a 3-year continuous rotation of wheat-barley-canola under the historic and future climates. The AEV falls from $117/ha to $95/ha in the future and the coefficient of variation increased slightly (Table 2.3).

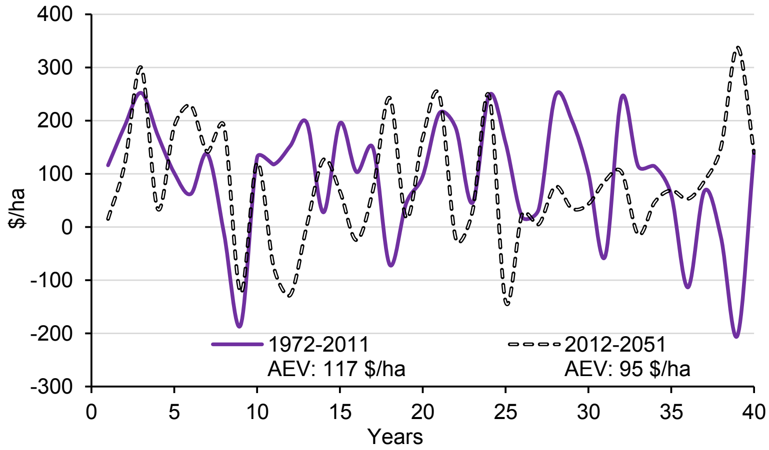


Figure 2.1 Cash flows for a wheat-barley-canola rotation: deep sandy duplex soil: historic and future climate: Cunderdin

The small change is profitable because grain crops grown in winter and spring are affected by both positively and negatively by the combination of higher minimum temperatures in winter, as well as the rise in maximum temperatures. The mean monthly rainfall charts (Figure 5.6) show that in some months rainfall is lower and in others it is higher, so there are gains and losses for crop yields and cash flows.

Table 2.3 Financial measures of cash flow for wheat-barley-canola rotations: deep sandy duplex soils: historic and future climate: Cunderdin

Period	1972-2011	2012-2051
NPV ($/ha)	1564	1267
AEV ($/ha/yr)	117	95
Min ($/ha)	-204	-140
Max ($/ha)	252	338
Std Dev (%/ha)	112	112
cv: Stdev/AEV	95%	118%

The distributions of cash flows are shown in Figure 2.2. These distributions indicate that in the best years profits are higher and in the worst years losses are not so bad in the future as in the past. The shape of the income distribution is changed in the future (see also Table 2.3).

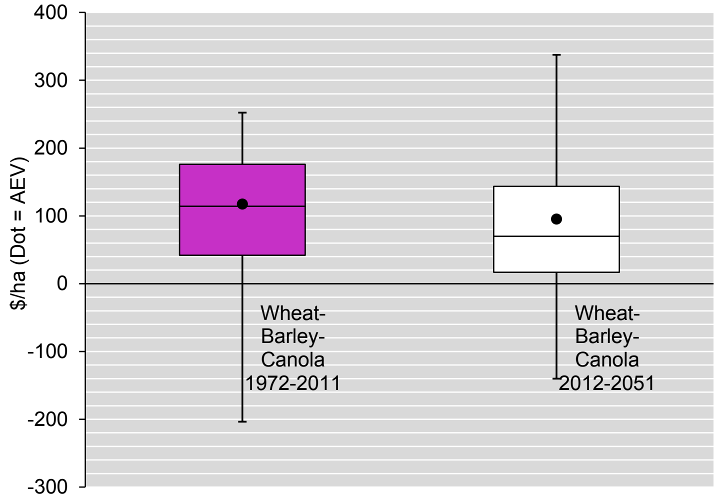


Figure 2.2 Distributions of cash flows for wheat-barley-canola rotations: deep sandy duplex soil: historic and future climate: Cunderdin

The results for the cash flows of mallees in the crop rotation for a future climate are shown in Figure 2.3. The AEV declined slightly with mallee. The summary statistics for this case are shown in Table 2.4 and the distribution graphs are in Figure 2.4.

Table 2.4 Financial measures of cash flow for wheat-barley-canola rotations: deep sandy duplex soil: with and without mallee: future climate: Cunderdin

Future Climate Scenario	Cropping Only	Cropping with mallee
NPV ($/ha)	1267	1225
AEV ($/ha/yr)	95	92
Min ($/ha)	-140	-132
Max ($/ha)	338	318
Std Dev (%/ha)	112	111
cv: Stdev/AEV	118%	121%

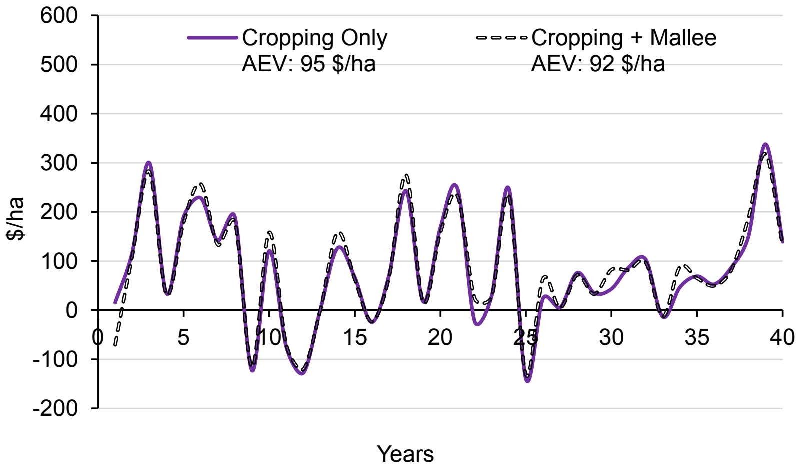


Figure 2.3 Cash flows for a wheat-barley-canola rotation: deep sandy duplex soil: with and without mallee: future climate: Cunderdin

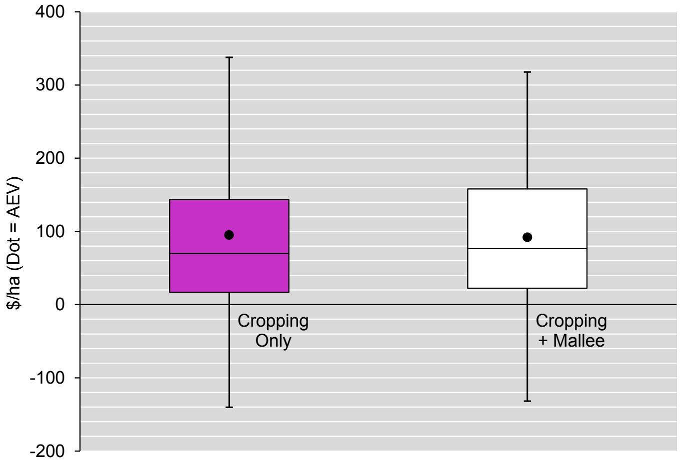


Figure 2.4 Distributions of cash flows for wheat-barley-canola rotations: deep sandy duplex soil: with and without mallee: future climate: Cunderdin

2.2.1.2.2 Pasture results

The first cash flow comparison is for annual pasture on deep sands for the current and future climates. These cash flows are in Figure 2.5, and the summary statistics are in Table 2.5. AEV is substantially reduced without any adaptation. This is further illustrated by the cash flow distributions in Figure 2.6.

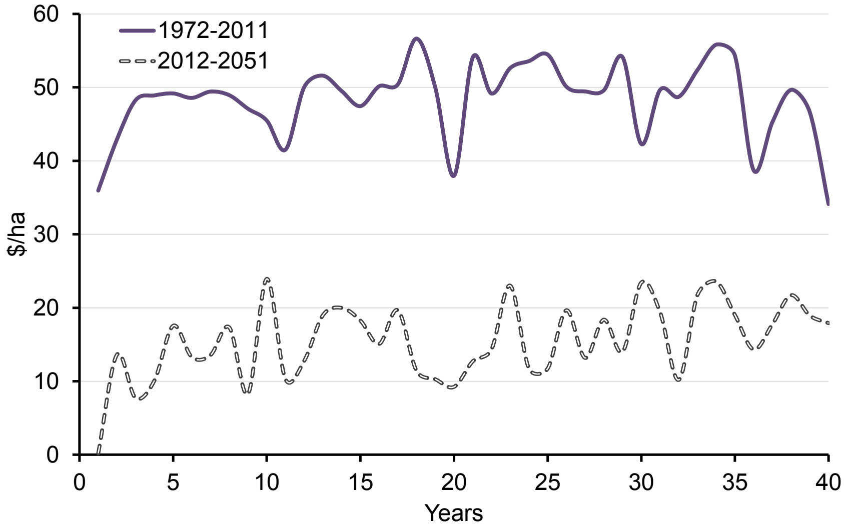


Figure 2.5 Cash flows for continuous annual pasture: deep sand soil: historic and future climate: Cunderdin

Table 2.5 Financial measures of cash flow for continuous annual pasture: deep sand soil: historic and future climate: Cunderdin

Period	1972-2011	2012-2051
NPV ($/ha)	678	194
AEV ($/ha/yr)	51	15
Min ($/ha)	34	0
Max ($/ha)	57	24
Std Dev (%/ha)	5	5
cv: Stdev/AEV	10%	36%

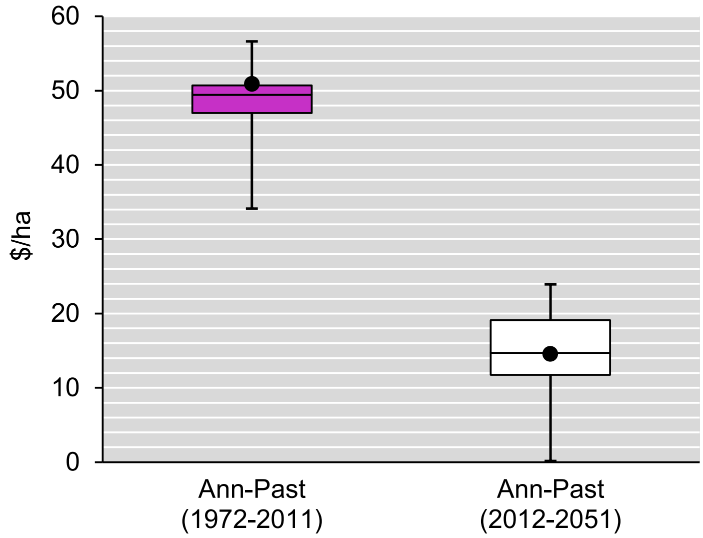


Figure 2.6 Distributions of cash flows for continuous annual pasture: deep sand soil: historic and future climate: Cunderdin

In the case of sheep grazing a continuous annual pasture paddock, the addition of mallee does not make much difference to AEV- a small increase from $15/ha to $16/ha. The cash flow results of this scenario are presented in Figure 2.7 and Table 2.6. The variability of cash flow increases substantially for annual pastures on these soils in the future climate scenario (compared to Table 2.5).

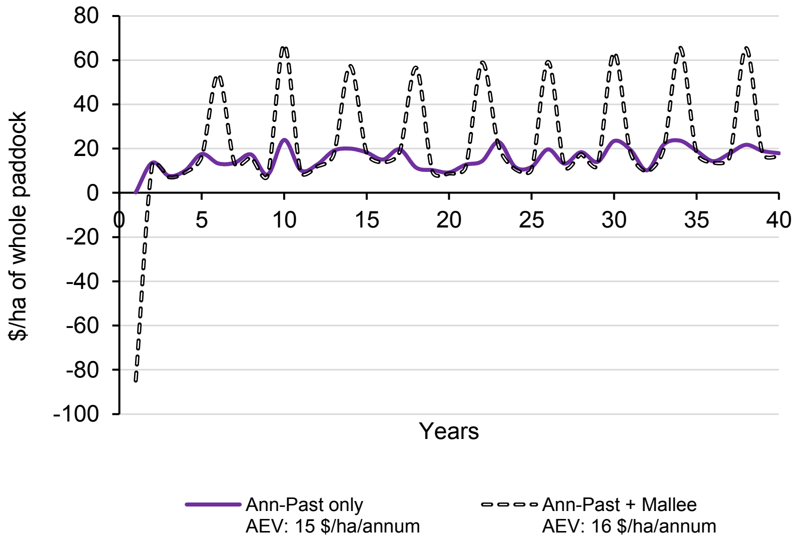


Figure 2.7 Cash flows for continuous annual pasture: deep sand soil: with and without mallees: future climate: Cunderdin

Table 2.6 Financial measures of cash flow for continuous annual pasture: deep sand soil: with and without mallees: future climate: Cunderdin

Period	Ann-Past Only	Ann-Past with Mallee
NPV ($/ha)	194	213
AEV ($/ha/yr)	15	16
Min ($/ha)	0	-85
Max ($/ha)	24	67
Std Dev (%/ha)	5	27
cv: Stdev/AEV	36%	167%

The final set of comparisons is of continuous perennial pasture on loamy sands at Cunderdin. Figure 2.8 presents the cash flows for this pasture in the historical and future climate and the summary statistics are in Table 2.7.

Table 2.7 Financial measures of cash flow for continuous perennial pasture: loamy sands: historic and future climate: Cunderdin

Period	1972-2011	2012-2051
NPV ($/ha)	1049	660
AEV ($/ha/yr)	79	50
Min ($/ha)	12	8
Max ($/ha)	131	88
Std Dev (%/ha)	23	20
cv: Stdev/AEV	30%	40%

The AEV falls from $79/ha to $50/ha in a changed climate without adaptation. The distribution of cash flow is shown in Figure 2.9.

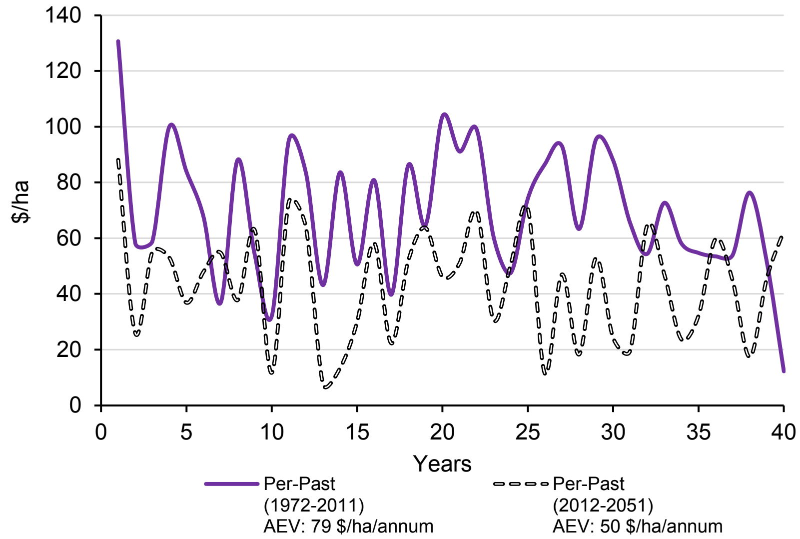


Figure 2.8 Cash flows for continuous perennial pasture: loamy sands: historic and future climate: Cunderdin

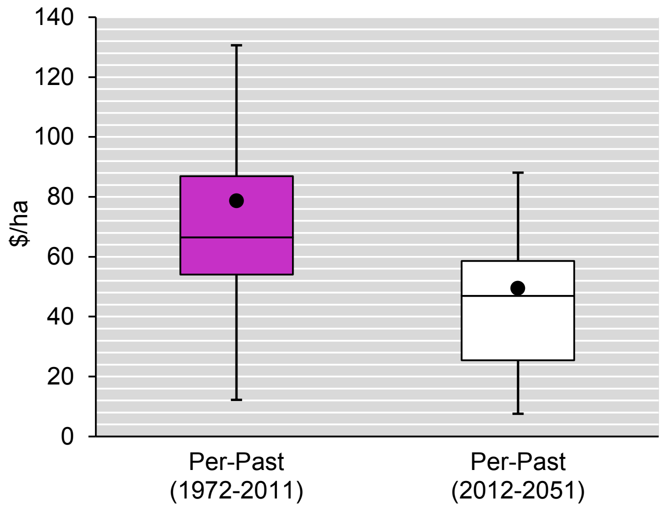


Figure 2.9 Distributions of cash flows for continuous perennial pasture: loamy sands: historic and future climate: Cunderdin

In the final analysis we assessed the cash flow effects of introducing mallees to continuous perennial pastures in a changed climate. The results are shown in Figure 2.10 and Table 2.8. The cash flow distributions are shown in Figure 2.11. As mallees are incorporated into a perennial pasture paddock in the future scenario there is little change observable in AEV but income variability increases due to period injection of income from mallee biomass.

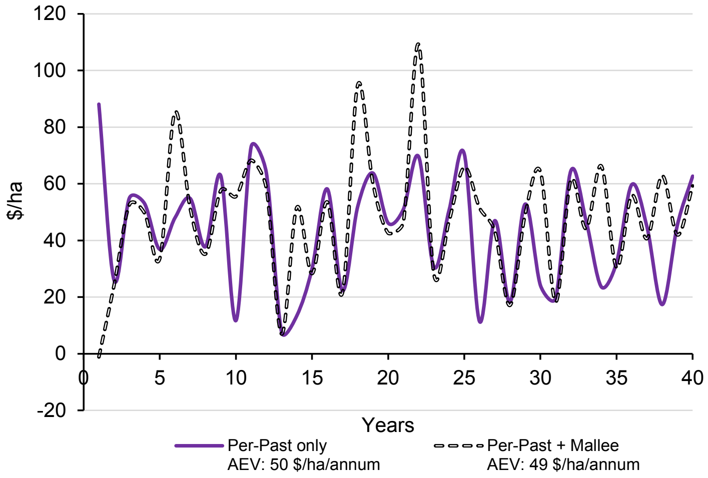


Figure 2.10 Cash flows for continuous perennial pasture: loamy sands: with and without mallees: future climate: Cunderdin

To validate the cash flow results estimated with IMAGINE we used information from Planfarm-Bankwest (2012) to calibrate our model, because both APSIM and GrassGro overestimate farm productivity in this region. Table 2.9 shows farm net returns from Planfarm-Bankwest (2012) benchmarks and the sheep net returns estimated from data in this report over the last 6 years. The average sheep industry return over the last 6 years was about $140/ha while sheep profitability was much less, at $25/ha.

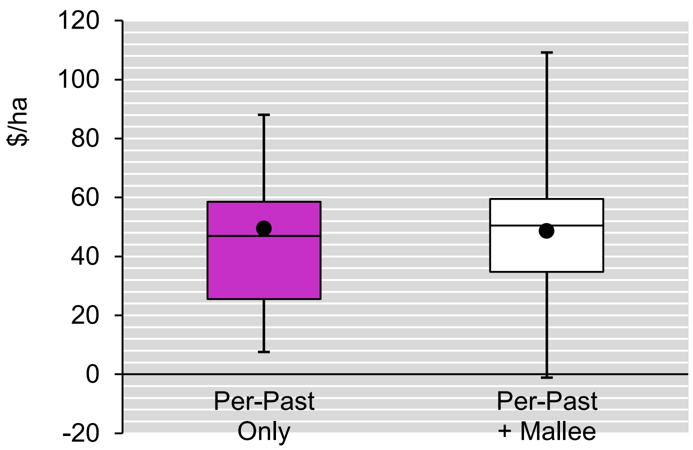


Figure 2.11 Distributions of cash flows for continuous perennial pasture: loamy sands: with and without mallee: future climate: Cunderdin

Table 2.8 Financial measures of cash flow for continuous perennial pasture: loamy sands: with and without mallee: future climate: Cunderdin

Period	Per-Past Only	Per-Past with Mallee
NPV ($/ha)	660	649
AEV ($/ha/yr)	50	49
Min ($/ha)	8	-1
Max ($/ha)	88	109
Std Dev (%/ha)	20	22
cv: Stdev/AEV	40%	45%

Table 2.9 Profitability of sheep farming from industry benchmarks (farm net return) and sheep net returns from this report: Cunderdin

Season	2006	2007	2008	2009	2010	2011
Sheep net return ($/ha)	56	40	-11	15	26	24
Farm net return ($/ha)	66	330	200	38	12	218

The Planfarm-Bankwest (2012) benchmarks show that the effective area cropped by Cunderdin growers was between75% and 80% with pasture area between 20% and 25% of the farm.

2.2.1.3 Summary for Cunderdin

For Cunderdin at the whole-farm level the effect of a changed climate (without adaptation) is likely to be a reduced farm income of ~20%. When perenniality options (pastures and mallees) were included as an adaptation option, the whole-farm income increased to slightly above the former (historic) level. However, the land use mix changed with the crop farm percentage being reduced to below 50% and perennial pastures and mallees occupying 20 – 30% of the farm in the future climate. Adaptation with perenniality and mallees seems to offer a means of maintaining farm income in the type of changed climate evaluated here. The marginal profit contributions of all soils types increased with perennial adaptation.

At the paddock level for the crop rotation considered here the AEV fell by ~20% without adaptation to the changed climate. When mallees were included in the changed climate the AEV was still slightly lower and income variability was still substantial.

At the paddock level for annual pastures the AEV fell substantially (70%) without adaptation. For perennial pastures there is still a reduction in AEV of over 30% in the future compared to the past. When full adaptation (perennial pastures and mallees) were assessed in the changed climate the AEV did not change substantially. In all cases the paddock-level cash flows exhibited increased variability in the future climate scenario.

The farm-level economic results for Cunderdin are summarised in Box 2.1.

Box 2.1: Cunderdin, WA

- ✓ Future climate impact without perennial innovation: ~20% reduction in farm profit;
- ✓ Extent and consistency of climate impact: Generally lower productivity across the whole farm;
- ✓ Impact of adoption of perennial pastures: a significant improvement in profitability of soils allocated to them, leading to modest improvement in whole farm profitability;
- ✓ Change in enterprise mix required for optimal contribution of perennials: A substantial reduction in cropping in favour of perennials while retaining the area allocated to annual pastures;
- ✓ Likely cash flow variability: More variable in the future, perennials improving the peaks without worsening the net returns in poor seasons.

2.2.2 Results for Katanning

2.2.2.1 Whole-farm results

The whole-farm results are shown in Table 2.10. In the base case (comprising of grain crops and annual pasture) the effect of a changed future climate is to increase whole-farm income by about $20/ha. This is due to the relatively improved performance of annual pastures under a changed climate. As perennials were added in both climates farm income increased and as mallee was added farm profit increased slightly more. Under a changed future climate the addition of perennials and mallee increased farm income to well above the historical base level.

Table 2.10 MIDAS whole-farm results: profit and land use: Katanning

	Percentage of farm area (%)					Farm Profit
	Crop	Annual pasture	Perennial pasture		Mallee	
			Lucerne	Tedera		$/ha
Historical climate						
Base	34	66	-	-	-	183
With PP	25	44	13	17	-	234
With PP & Mallee	25	33	13	26	3	237
Future climate						
Base (no PP)	25	75	-	-	-	205
With PP	13	35	36	16	-	274
With PP & Mallee	13	25	35	25	2	276

The proportion of farm area in crop and annual pasture was 34:66 in the base case, and this land use mix accords with typical farms in the Central Wheat Belt of Western Australia (Planfarm-Bankwest 2012). This mix changed in the future climate scenario to 25:75. When perennials and mallee were introduced they accounted for 42% of farm area in the historical climate and 62% in the future climate. The proportion of farm area in mallee was 2-3%.

The LMU areas, optimal rotations and MVPs for the future climate with perennial pastures and mallee are in Table 2.11. As expected, the poorer soils (LMUs 1 and 2) have the lowest MVPs. Lucerne is used in rotations on LMUs 4 and 5, tedera is on LMUs 1, 3 and 5, and mallee is adopted on LMUs 1 and 2.

Table 2.11 MVPs (profit contribution) of land use on LMUs: with perennial pastures & mallee: future climate: Katanning

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	100	146	Tedera and mallee
2	150	218	Continuous pasture and mallee
3	50	318	Tedera
4	500	368	4 yr lucerne, 1 yr wheat, 5 yr pasture, 2 yr cereal
5	200	410	4 yr lucerne, 1 yr wheat, 5 yr pasture, 2 yr cereal, tedera

2.2.2.2 Paddock-level results

Paddock-level results for Katanning are presented for two soil types – LMU 3 (deep sand) for pastures for wool production and LMU 5 (sandy loams) for crop rotations.

2.2.2.2.1 Pasture results

Figure 2.12 contains the cash flow comparison for LMU 3 of annual ryegrass and sub-clover under each climate scenario and Table 2.12 contains the summary statistics for those cash flows.

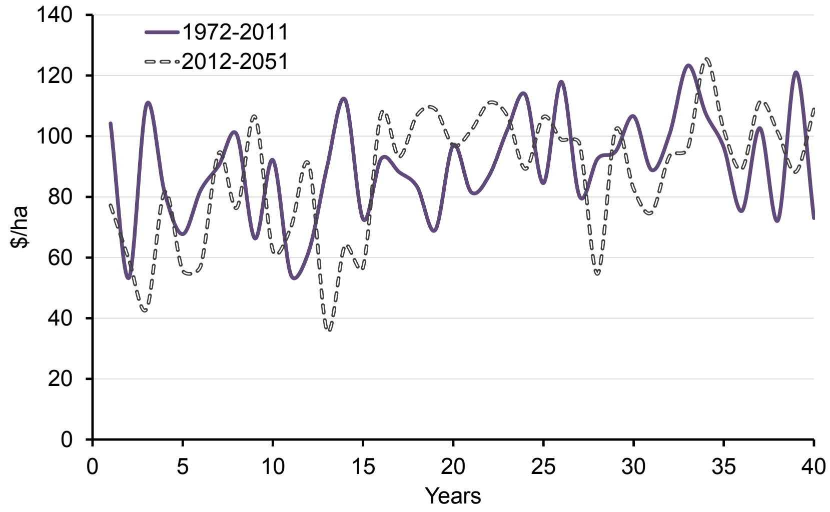


Figure 2.12 Cash flow and financial results for annual ryegrass and sub-clover pasture: historic and future climates: LMU 3: Katanning

Table 2.12 Summary statistics for cash flow and financial results for annual ryegrass and sub-clover pasture: historic and future climates: LMU 3: Katanning

Period	1972-2011	2012-2051
NPV ($/ha)	1229	1118
AEV ($/ha/annum)	92	84
Min ($/ha)	53	36
Max ($/ha)	123	125
Std Dev (%/ha)	18	21
cv: Stdev/AEV	19%	26%

From Figure 2.12 and Table 2.12 for the base case of annual pastures, long-term paddock profitability is expected to decline by 9% without adaptation and income variability increases.

Figure 2.13 contains the cash flows when mallees are added to annual pastures for the past and future climates and the cash flow distributions are in Figure 2.14. With the addition of mallees to annual pastures in the future the AEV increases slightly but income variability increases substantially.

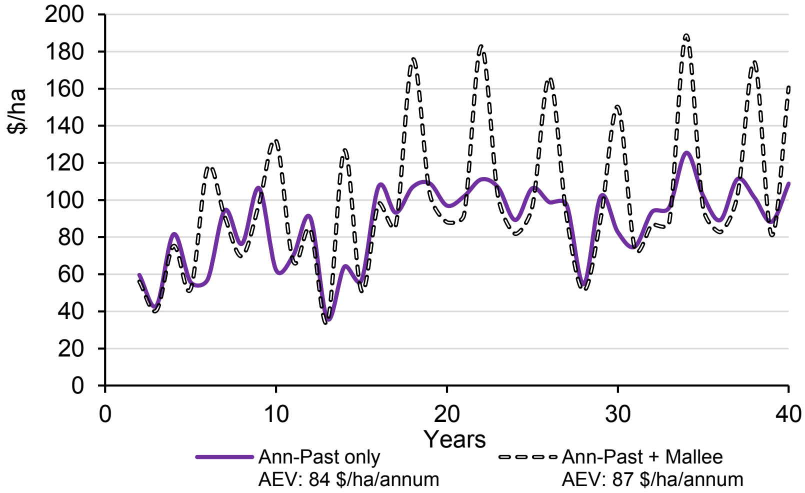


Figure 2.13 Cash flow and financial results for annual ryegrass and sub-clover pasture with and without mallee: future climate: LMU 3: Katanning

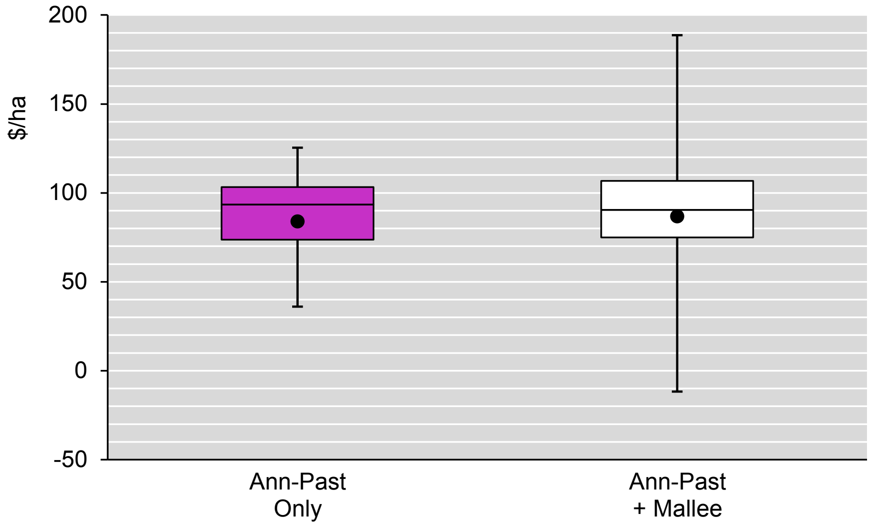


Figure 2.14 Continuous annual pasture with and without mallees: LMU 3: future climate: Katanning

Perennial pastures (lucerne) and mallees were also analysed at the paddock level. Mallee biomass yields are shown in Chapter 7 (Table 7.9).

Cash flows for perennial pasture (lucerne) with and without mallee in the future climate are shown in Figure 2.6 and summary statistics are in Table 2.13. Long-term paddock profitability is reduced from $205/ha to $199/ha with no change in income risk.

The distributions of cash flow income for perennial pasture (lucerne) with and without mallee in the future climate are shown in Figure 2.16. There is little change in between these distributions.

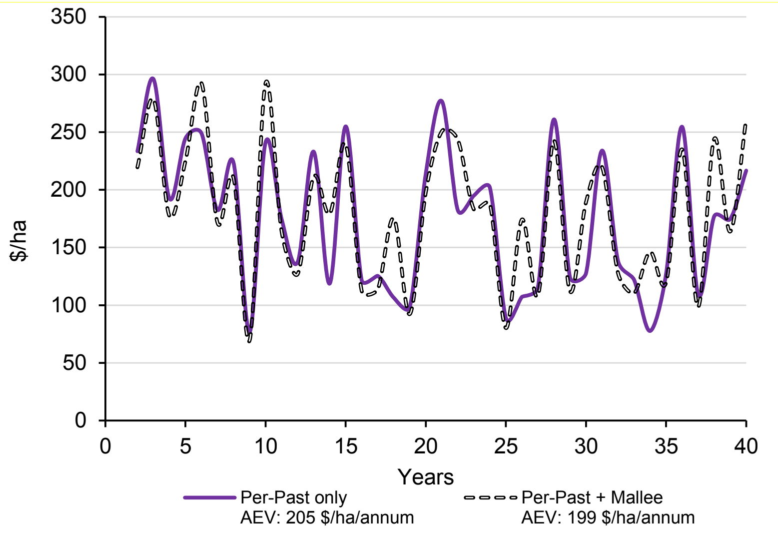


Figure 2.15 Cash flow and financial results for perennial pasture (Lucerne) with and without mallee: future climate scenario: LMU 3: Katanning

Table 2.13 Perennial pasture (Lucerne) with and without mallees: future climate: LMU 3: Katanning

Period	Perennial Pasture Only	Perennial Pasture with Mallee
NPV ($/ha)	2738	2655
AEV ($/ha/annum)	205	199
Min ($/ha)	77	69
Max ($/ha)	296	293
Std Dev (%/ha)	62	62
cv: Stdev/AEV	30%	31%

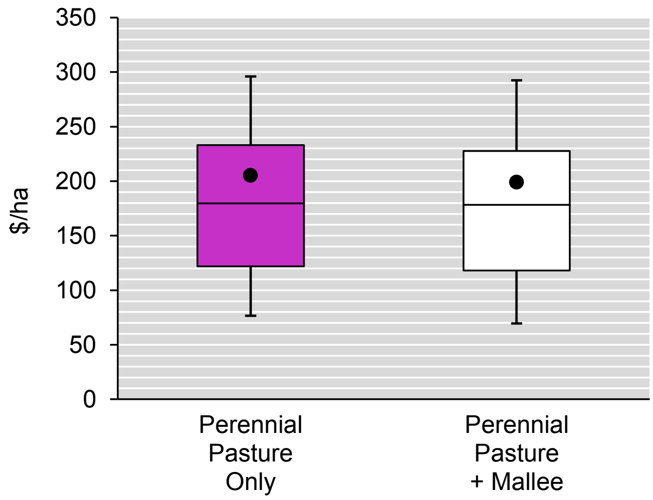


Figure 2.16 Continuous perennial pasture (lucerne) with and without mallees: LMU 3: future climate: Katanning

2.2.2.2.2 Cropping results

For cropping a wheat-barley-canola rotation was investigated for sandy loam soils (LMU 5). The cash flows in the historic and future climates are in Figure 2.17. Summary financial statistics for these cases are in Table 2.14. The effects on income distributions are in Figure 2.18.

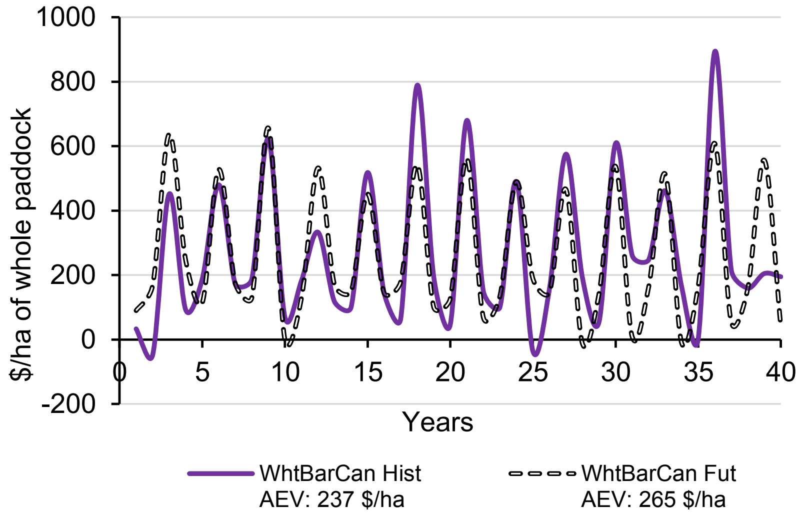


Figure 2.17 Cash flow and financial results for a wheat-barley-canola rotation: historical and future climates: LMU 5 at Katanning

Table 2.14 Wheat-barley-canola rotation: historic and future climates: sandy loams (LMU 5): Katanning

Period	1972-2011	2012-2051
NPV ($/ha)	3379	3776
AEV ($/ha/annum)	253	283
Min ($/ha)	-48	-13
Max ($/ha)	894	656
Std Dev (%/ha)	233	213
cv: Stdev/AEV	92%	75%

For this rotation and soil type the future cash flows are predicted to be improved compared to the past in terms of the AEV (an increase from $253/ha to $283/ha) and income variability (CV is lower in the future scenario).

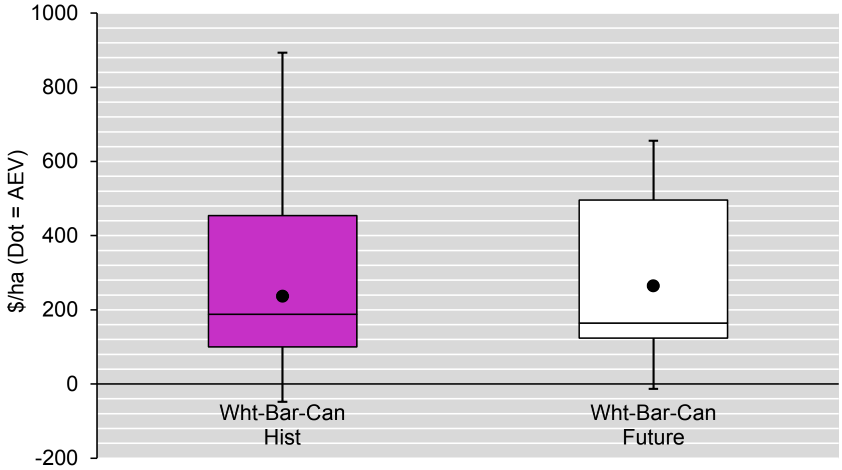


Figure 2.18 Wheat-barley-canola rotation: historical and future climate climates: sandy loams (LMU 5): Katanning

2.2.2.3 Summary for Katanning

For Katanning at the whole-farm level the effect of a changed climate was that farm income increased by ~10% due to changed seasonal rainfall patterns. When adaptation options (perennial pastures and mallees) were added farm income increased in each climate scenario, but there was a change in land use with the areas of crop and annual pasture being reduced and areas of lucerne, tedera and mallees increasing (to over 60% of the farm).

At the paddock level for crops the AEV increased by over 10% under the changed climate with reduced income variability. For pastures without adaptation the annual pasture AEV was reduced under the changed climate and income variability increased. The addition of mallees to perennial pastures slightly increased the AEV but the effect of mallees with perennials was negligible.

The farm-level economic results for Katanning are summarised in Box 2.2.

Box 2.2: Katanning, WA

- ✓ Future climate impact without perennial innovation: 10% improvement in whole-farm farm profit due to more favourable growing conditions in winter and spring;
- ✓ Extent and consistency of climate impact: not uniform across the whole farm; with increase in profitability of annual and perennial pastures and reduced profitability of cropping;
- ✓ Impact of adoption of perennial pastures: a significant improvement in profitability of soils allocated to them, leading to significant improvement in whole farm profitability;
- ✓ Change in enterprise mix required for optimal contribution of perennials: A shift to less cropping and reduced area of annual pastures in favour of perennials;
- ✓ Likely cash flow variability: Less variable in the future, with occasional poor seasons being worse in economic terms than the past; perennials improving the peaks without worsening the net returns in poor seasons.

2.2.3 Results for Wagga Wagga

The economic results for Wagga Wagga were only derived at the paddock level from IMAGINE.

2.2.3.1 Pasture results

Figure 2.19 shows the cash flows associated with livestock grazing of annual pastures in the historical and future scenarios. There are substantial variations in cash flows from year to year. As experienced in practice, there are periods when a sequence of below average seasons prevails. It is worth noting that for the sake of ease of interpretation of data and parsimony in explaining our findings we have excluded the impact of market conditions for wool, meat, and inputs which exacerbate these results for growers in practice. In some situations a poor season, from rainfall point of view, may compensate the farmer with higher commodity prices dampening the negative impact of a poor season.

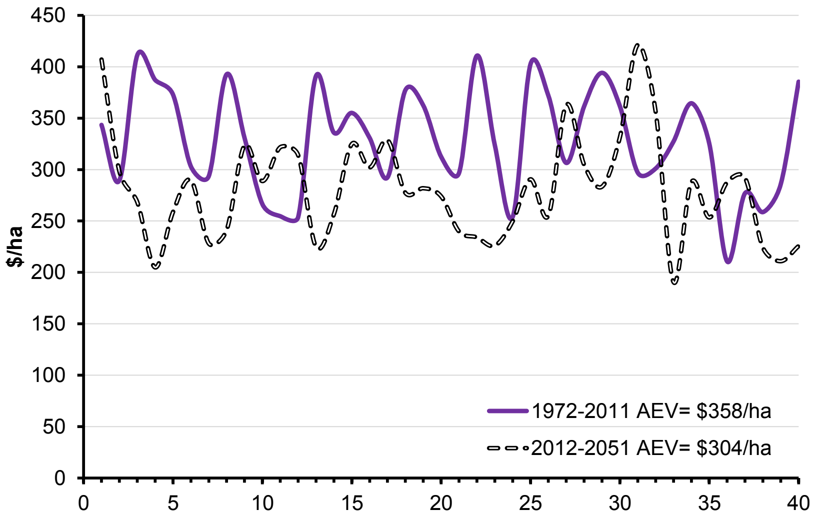


Figure 2.19: Profitability of combination of annual pasture in the historical and future scenarios: Wagga Wagga

The AEV of annual pastures across the farm indicates the expected farm net return where only annual pastures are used for livestock grazing in combination with supplementary feeding of grain is $358 in the historical scenario. Expected profitability is reduced by $54/ha in the future scenario if the farm continues with only annual pastures.

For a variety of reasons a significant proportion of farmers generate only half or less of the profits that are estimated in this study. Other factors which reduce net returns of livestock grazing on pastures are the periodic establishment costs that can be between $200 to $300/ha which is excluded from this analysis. We have assumed continuous pasture with some pasture maintenance without reseeding or renovation being costed. Renovation can cost from $100-150/ha once every 5-10 years. These have to be accounted for and are other factors that are involved in reducing the profitability of pasture below that found in modelling studies such as this. The rationale for this approach was to avoid introducing additional complications or modifiers (noise) into the trends associated with production of pasture and livestock as a function of climate.

Readers should consider not just the absolute income levels but rather the magnitude of variability between poor and good seasons as well as the difference between the past and future and a farm with annual pastures only versus one which incorporates perennial pastures.

Table 2.15: Summary statistics for net returns for a farm in Wagga Wagga: annual pastures

	1972-2011	2012-2051
NPV ($/ha)	4771	4059
AEV ($/ha/yr)	358	304
Min ($/ha)	211	191
Max ($/ha)	411	421
Std Dev (%/ha)	51	52
cv: Std Dev/AEV	14%	17%

Figure 2.20 shows the cash flows associated with livestock grazing of pastures as perennials are added in the historical and future scenarios. The AEV is lower in the future than the past. There can be as much as $200 per hectare difference between seasons. As experienced in practice there are periods when a sequence of below average seasons prevails. Periods such as years 3 to 8 and years 20 to 28 are examples of sequences of seasons with below average profitability

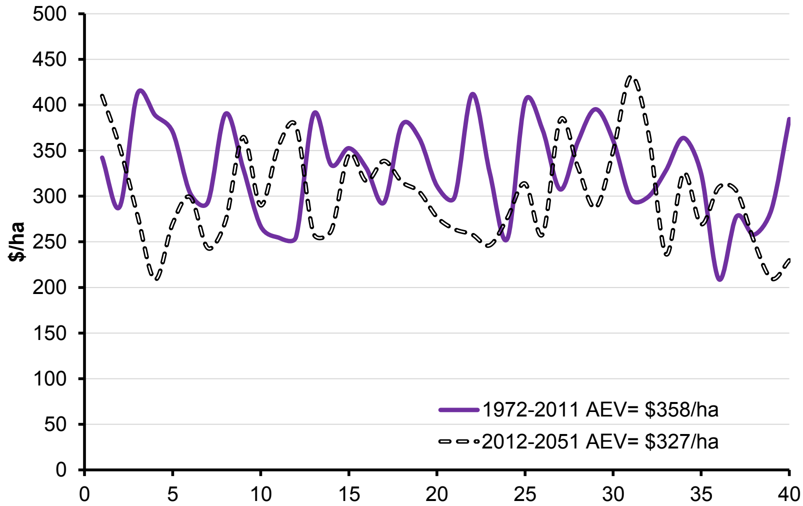


Figure 2.20 Profitability of combination of annual and perennial pastures (phalaris and lucerne): historical and future scenarios: Wagga Wagga

Long-term farm profitability attributable to the combination of annual and perennial pastures is $358 in the historical scenario (Table 2.16). Profitability is reduced by close to $30/ha in the future scenario.

Comparing the future scenario with and without perennial pastures shows that adoption of perennial pastures (phalaris and lucerne) in combination with annual pastures can add another $23/ha to farm profitability without increasing the variability of net returns or exposing to lower profits in poor seasons (Table 2.15 and 2.16). Combining annual and perennial pastures results in decline of variability in net returns. Note supplementary grain feeding of sheep is still necessary on a farm with a mix of annual and perennial pastures.

Table 2.16 Summary statistics for a mix of annual and perennial pastures: Wagga Wagga

Period	1972-2011	2012-2051
NPV ($/ha)	4768	4354
AEV ($/ha/yr)	358	327
Min ($/ha)	209	209
Max ($/ha)	412	431
Std Dev (%/ha)	51	54
cv: Stdev/AEV	14%	16%

The chart in Figure 2.21 shows the financial contribution of each pasture in each year. There are substantial differences between pastures in their response to seasons. Phalaris did very poorly in two of the 40 years (years 3 and 38) when its contribution to farm profit was less than $10/ha while annual pasture (ryegrass and sub-clover) and lucerne each contributed over $110/ha. This is caused mainly by the cumulative effect of a series of daily rainfall events and its impact on the growth of the each pasture type. In the third year of the future scenario there were very few days with enough rainfall for adequate plant productivity causing particularly low carrying capacity in phalaris. The same was true for annual pasture in year 38.

Phalaris and annual pastures have coefficients of variation close to 30% while lucerne has a coefficient of variation close to 20%. However, combination of all three types of pastures results in a coefficient of variation of 16%, indicating that the portfolio of annual and perennial pastures reduces the variability of income. Our analysis of past and future profitability of pastures shows that the risk-reducing impact of a portfolio of annual and perennial pastures is more important in the future scenario than in the past.

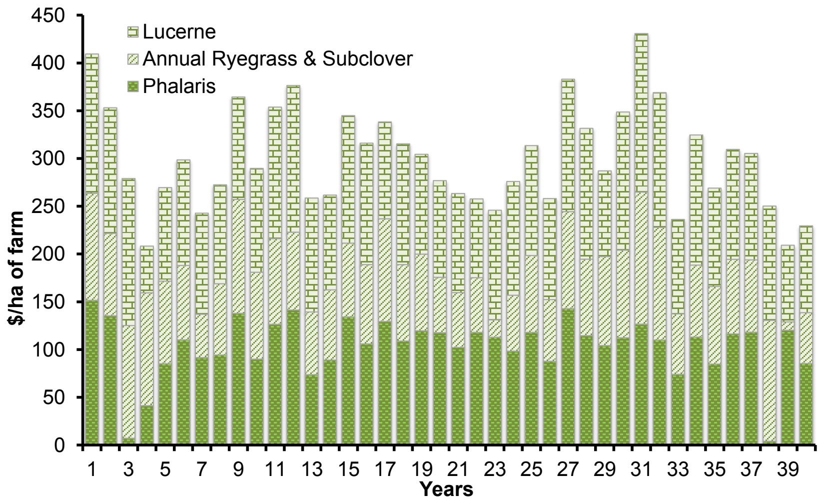


Figure 2.21 Seasonal variability of net returns per hectare in Wagga Wagga and the contribution of each pasture type to farm profitability in the future climate scenario: future climate

Figure 2.22 contains information about when trees are introduced as belts (occupying 6% of the paddocks) into pasture paddocks, consisting of both annual and perennial pastures. This leads to a modest improvement in farm profitability. Trees are harvested in years 6, 10, and so on every four year after planting.

The cash flow chart of net returns shown Figure 2.8 is a combination of returns from livestock grazing of annual and perennial pastures, with and without mallee tree belts dispersed across the farm on pasture paddocks. The cash flow peaks in the years 6, 10, 18, 22, and 34 for cash flows including mallees indicate that in those seasons harvest and income of mallees provided significant improvement in profitability compared to the system without mallees. In that scenario tree belts provide income diversification which reduced revenue risk, by conferring a buffer against seasonal variability which substantially reduced profitability of the livestock enterprise.

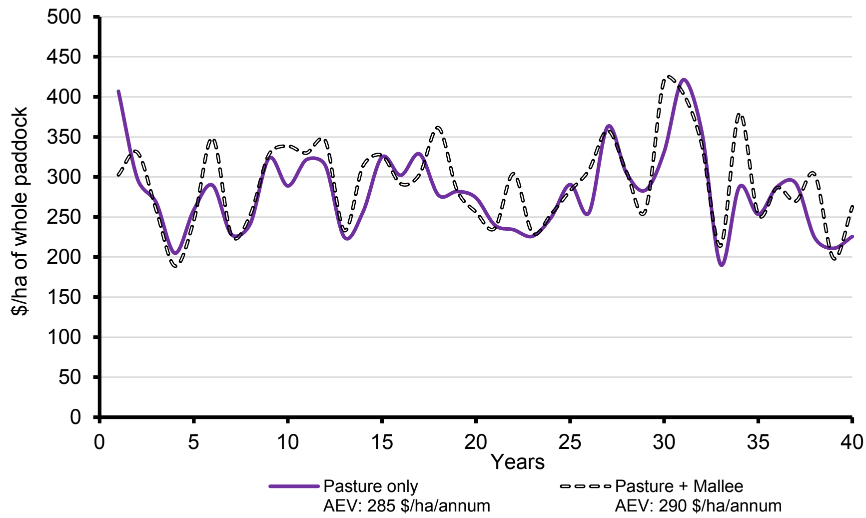


Figure 2.22 Seasonal net returns at Wagga Wagga for a paddock with annual and perennial pastures with and without mallee tree belts: future climate: belts occupy 6% of the land

A summary of the cash flow distributions (Figure 2.23) illustrates that mallees slightly improve long term expected farm profit (i.e. AEV of net returns) by increasing income in seasons of harvest for mallees without exacerbating the losses in poor seasons.

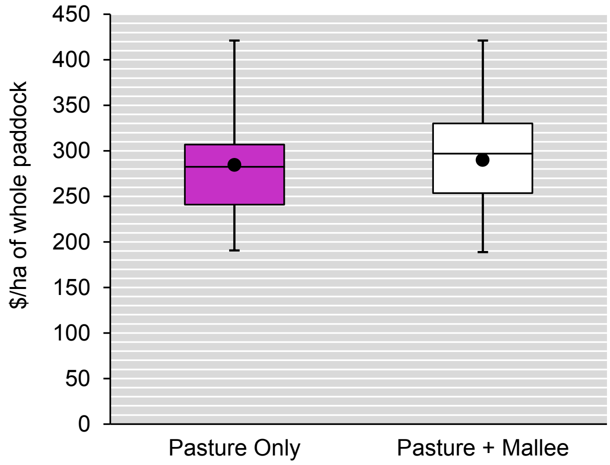


Figure 2.23 Profitability of livestock grazing at Wagga Wagga: pasture only compared with mallee biomass trees incorporated as belt crops into pasture: future climate

2.3.3.2 Cropping results

We investigated the cash flow of a six-year continuous rotation of wheat-barley-canola-wheat-barley-field pea for the historic and future climates at Wagga Wagga. The yields were adjusted for yield gaps between farmer paddock yields and those estimated by ASPSIM (Fiona Scott, NSW DPI pers. comm.). The comparisons presented are of this crop rotation in historic and future climates and the crop rotation with and without mallees in the future climate.

The AEV was $149/ha in the historical scenario and $48/ha lower under the future climate scenario (Figure 2.24). The inter-year variation in net returns was close to $900/ha in the historical scenario and $830/ha in the future climate scenario. Similarly, the standard deviation of net returns was $227/ha and $184/ha for the historical and future climate scenarios. Comparison of the variability of net revenues of livestock reported above and that of crops indicates that cropping is much riskier in Wagga Wagga than livestock grazed on pastures.

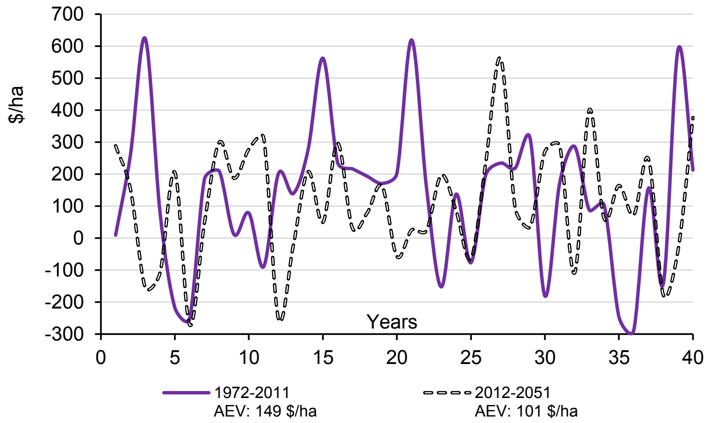


Figure 2.24 Cash flow of net returns: continuous wheat-barley-canola-wheat-barley-field pea: historical and future climate: Wagga Wagga

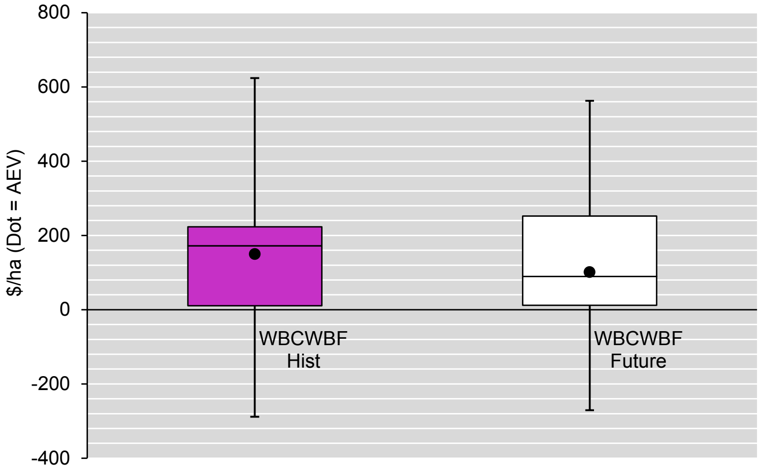


Figure 2.25 Profitability of continuous cropping: rotation of wheat-barley-canola-wheat-barley-field pea: future climate: Wagga Wagga

In the future climate scenario, addition of mallee tree belts into paddocks with continuous cropping marginally improved net returns ($101 compared to $108/ha, see Figure 2.26 and Table 2.17). Addition of mallees for biomass can improve the net revenues in some years. In low income years, mallees can sometimes reduce the losses.

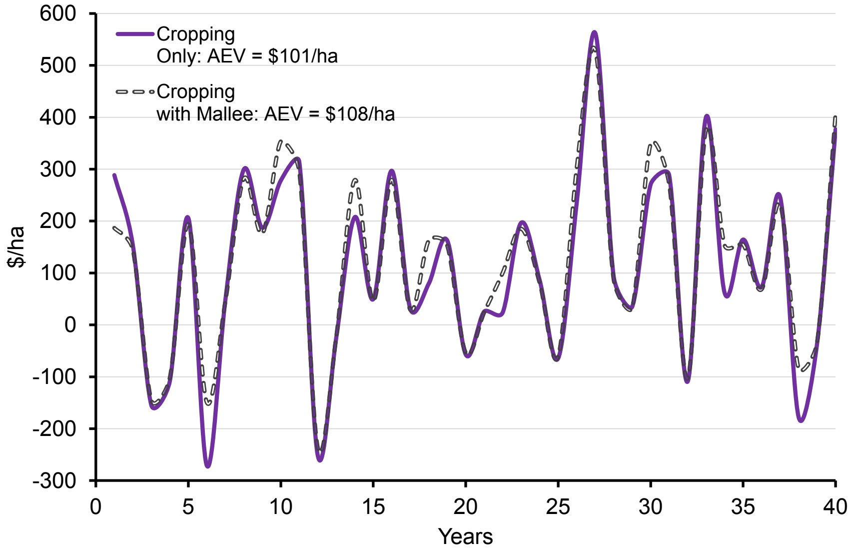


Figure 2.26 Cash flow from rotation of wheat-barley-canola-wheat-barley-field pea with and without mallee tree belts: Wagga Wagga: future climate

Summary statistics for these cash flows are in Table 2.17. The maximum net income when mallees were included was lower; however, the minimum income (associated with crop losses) was higher. Mallee will therefore reduce the riskiness of cropping in years with negative incomes when the trees are harvested to generate positive net revenues when the grain crops are losing money.

Table 2.17 Summary statistics for cash flows from rotation of wheat-barley-canola-wheat-barley-field pea with and without mallee tree belts: Wagga Wagga: future climate

Future Climate Scenario	Cropping Only	Cropping with Mallee
NPV ($/ha)	1352	1443
AEV ($/ha/yr)	101	108
Min ($/ha)	-271	-237
Max ($/ha)	563	529
Std Dev (%/ha)	184	174
cv: Stdev/AEV	182%	161%

2.3.3.3 Summary for Wagga Wagga

Farm financial results were developed for Wagga Wagga using IMAGINE for particular soils and enterprises. For a continuous crop rotation the effect of a changed climate without adaptation is to reduce the AEV by over 30%. When mallees were added the AEV was only increased by less than 10%, and income variability declined slightly.

For annual pastures without adaptation the AEV was reduced by 15% under a changed climate. When perennial pastures were added the AEV reduction was less (just under 10%). When mallees were added to the annual and perennial pasture mix the AEV and income variability were largely unchanged.

The farm-level economic results for Wagga Wagga are summarised in Box 2.3.

Box 2.3: Wagga Wagga, NSW

- ✓ For pastures and livestock at the paddock level, long term profitability (AEV) is reduced without adaptation but this decline is reduced when perennial pastures are included;
- ✓ The portfolio of annual plus perennial pastures reduces the variability of income;
- ✓ The inclusion of mallees with pasture slightly increases long-term paddock income;
- ✓ For cropping at the paddock level, the effect of climate change is to reduce long-term profitability by over 30%;
- ✓ Inclusion of mallees leads to a smaller reduction in profitability and improves the downside risk in years of negative crop income.

2.2.4 Results for Hamilton

At Hamilton the existing MIDAS did not include crops; hence the whole-farm analysis is of pastures under a changed climate. And the existing pasture mixes in this region already include some perennials. The pasture comparisons in MIDAS were based on the FFI CRC EverGraze® project (Future Farm Industries CRC 2012) which analysed three pasture species or systems: 'Current', 'High Perennial Ryegrass' and 'Triple system of lucerne, tall fescue and perennial ryegrass'.

In this analysis the base pastures were continuous perennial pastures consisting of kikuyu, perennial ryegrass and sub-clover, and the improved perenniality options were these pastures plus fescue and lucerne (see Table 7.10). Thus the improved perenniality matched the 'Triple' system in the EverGraze project.

Sheep flock types analysed were traditional merino wool, wool-meat merino, wool-meat merino self-replacing with terminal sire, and first cross ewes.

Some landholders in Hamilton have adopted cropping. The paddock-level analyses were of changes in both pasture/livestock and cropping enterprises. Tocker and Berrisford (2011) present cropping enterprise analysis for this region. Hence, the IMAGINE paddock-level analysis included cropping options in terms of cash flows.

2.2.4.1 Whole-farm results

The whole-farm results are in Table 2.18. In the base case (base perennial pasture) the effect of a changed future climate was to decrease whole-farm income by 15%. This is due to the relatively poorer performance of existing perennial pastures under a changed climate. As new perennials were added under both climates farm income increased and as mallee was further added farm profit increased slightly more. Under a changed future climate the addition of perennials and mallee increased farm income slightly above the historical base level.

Table 2.18 MIDAS whole-farm results: profit and land use: Hamilton

	Percentage of farm area (%)			Farm Profit
	Base perennials	Fescue & Lucerne	Mallee	$/ha
Historical climate				
Base (no PP)	100	-	-	300
With PP	80	20	-	345
With PP & Mallee	75	19	6	347
Future climate				
Base (no PP)	100	-	-	255
With PP	80	20	-	308
With PP & Mallee	75	19	6	310

In the base case the entire farm area was dedicated to existing pasture swards consisting of a kikuyu, perennial ryegrass and sub-clover. This land use mix accords with typical farms in south-western Victoria (Tocker and Berrisford 2011). This mix was unchanged in the future climate scenario. When new perennials (fescue and lucerne) and mallee were introduced they accounted for 25% of farm area in both climates. The proportion of farm area in mallee was 6%.

The LMU areas, optimal rotations and MVPs for the future climate with perennial pastures and mallee are in Table 2.19. The poorer soils (LMUs 1 and 2) have the lowest MVPs. When introduced to the model farm system fescue and mallees were profitable enough to be included as part of the land use sequence of all LMUs. The MVPs for each LMU are generally higher than at the other locations.

Table 2.19 MVPs (profit contributions) of land use on LMUs: with perennial pastures & mallee: future climate: Hamilton

LMU/Soil	Area (ha)	MVP ($/ha)	Rotations selected and (area allocated)
1	200	379	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover with mallee belts on 6%
2	600	366	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover with mallee belts on 6%
3	200	503	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover with mallee belts on 6%

2.2.4.2 Paddock-level results

2.2.4.2.1 Pasture results

Merino meat and wool flocks were the livestock enterprises analysed on pastures. The cash flows for the base perennial pastures under each climate are shown in Figure 2.27. Under the future climate paddock profitability (AEV) is substantially reduced (by nearly 80%). This is due to more frequent adverse seasonal conditions requiring more supplementary feeding of stock or agistment. Supplementary feeding costs are the main cause of this income decline. In this analysis a restriction on the level of supplementary feeding was imposed to represent the situation where graziers would find agistment rather than spend very large amounts of cash on supplementary feed.

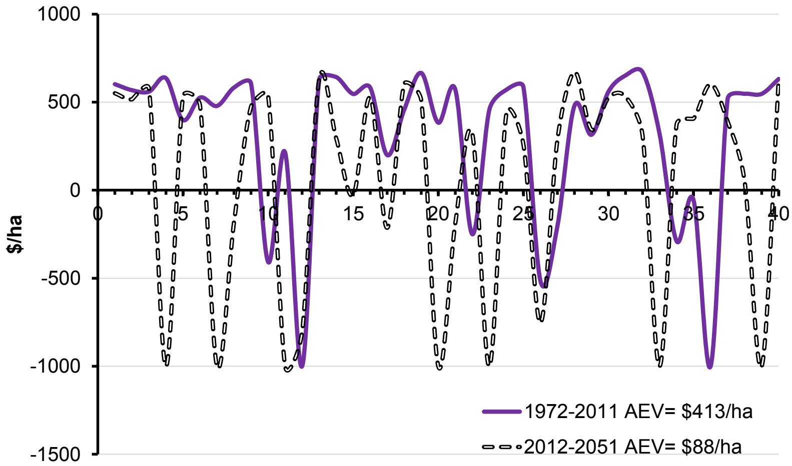


Figure 2.27 Cash flows for base perennial pastures: historical and future scenarios: Hamilton

When mallees were included with this base case the cash flow pattern was as shown in Figure 2.28.

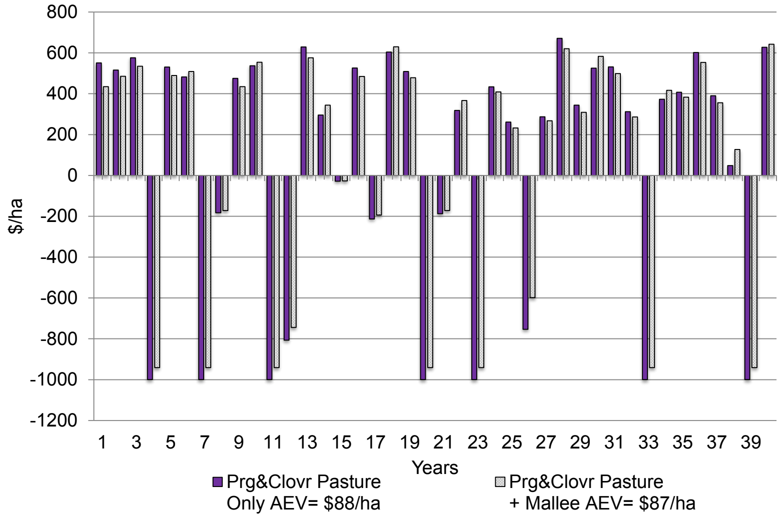


Figure 2.28 Cash flows for base perennial pastures: with and without mallees: future climate: Hamilton

The addition of mallees did not change the AEV. The summary statistics for this comparison are in Table 2.20. Income variability is substantial.

Table 2.20 Summary statistics for cash flows from base perennial pastures: with and without mallees: future climate: Hamilton

Period	Perennial ryegrass & sub-clover Pasture Only	Perennial ryegrass & sub-clover with mallee
NPV ($/ha)	1167	1161
AEV ($/ha/yr)	88	87
Min ($/ha)	-1000	-941
Max ($/ha)	671	642
Std Dev (%/ha)	605	570
cv: Stdev/AEV	691%	654%

The cash flow patterns of improved perennial pastures and mallees are shown in Figure 2.29. The net returns (AEV) are virtually unchanged when mallees are added, but these incomes are higher than for the base pastures in Table 2.13.

The summary statistics for this comparison are shown in Table 2.21. Income variability is still high but relatively unchanged when mallees are added.

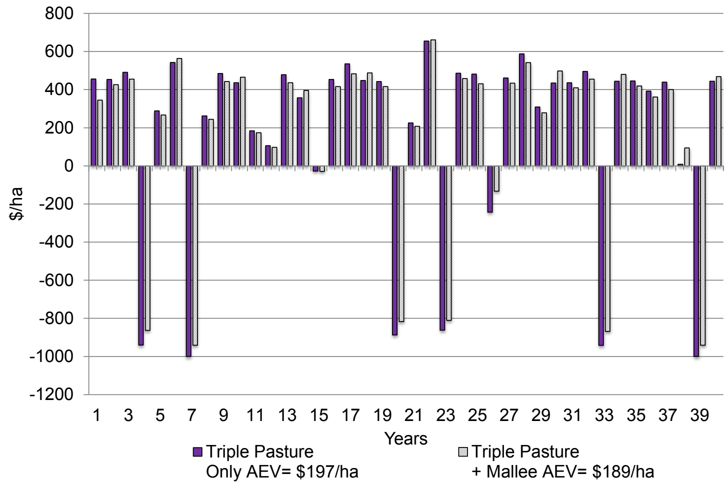


Figure 2.29 Cash flows for Triple pasture system: with and without mallee: future climate: Hamilton

Table 2.21 Summary statistics for cash flows from Triple pasture system: with and without mallees: future climate: Hamilton

Period	Triple Pasture only	Triple Pasture + Mallee
NPV ($/ha)	2620	2525
AEV ($/ha/annum)	197	189
Min ($/ha)	-1000	-941
Max ($/ha)	655	661
Std Dev (%/ha)	507	476
cv: Stdev/AEV	258%	251%

2.2.4.2.2 Cropping results

The crop rotation analysed was a three-year cycle of wheat-wheat-canola. The cash flow patterns for this rotation under historical and future climates are in Figure 2.30. Under the future climate AEV is reduced by 25%, but the variability of income is reduced substantially (Figure 2.31).

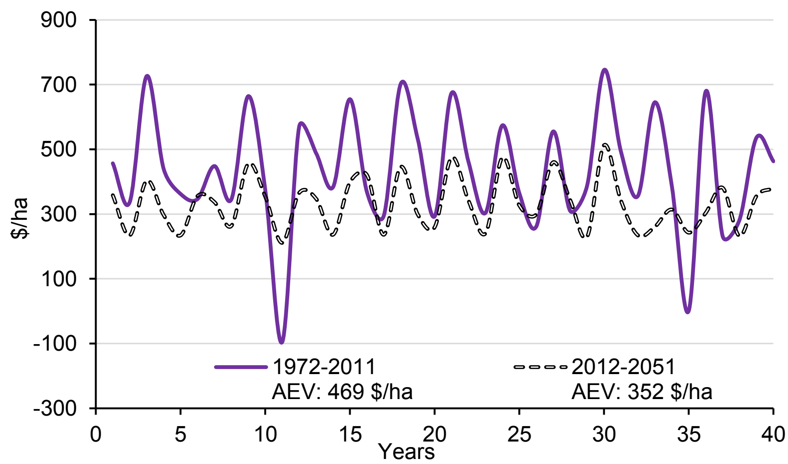


Figure 2.30 Cash flows for three-year cereal rotation: historical and future climate: Hamilton

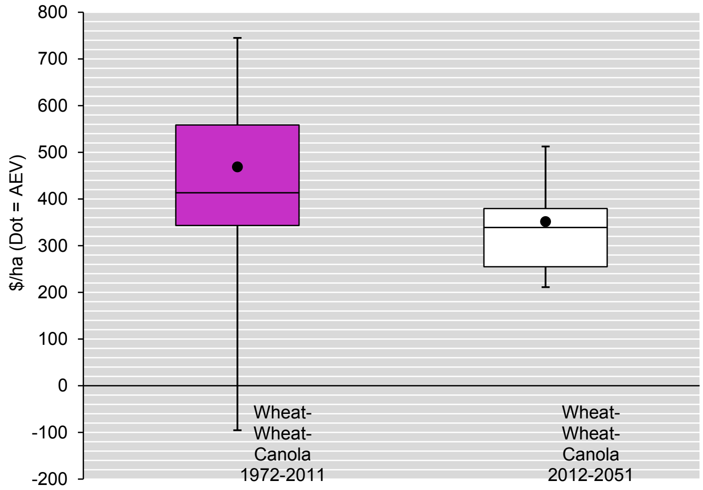


Figure 2.31 Profitability of three-year cereal rotation: historical and future climate: Hamilton

2.2.4.3 Summary for Hamilton

The whole-farm results for the base pasture-livestock activities were that farm income reduced by 15% in a future climate without adaptation. As the Triple pasture system plus mallees were added the farm profit was returned to the previous levels, and these activities occupied about a quarter of the farm.

The paddock-level results showed that without adaptation, the AEV of the base perennial system would be reduced by nearly 80%. Income variability was very high due to the need for supplementary feeding of livestock in drought years. When the improved perennial (Triple) system was tested income was still reduced substantially (to 50% of the historical level) and income variability remained very high.

The paddock analysis of a three-year crop rotation showed that without adaptation the AEV would be reduced by 25%, but income variability is substantially reduced.

The farm-level results for Hamilton are summarised in Box 2.4.

Box 2.4: Hamilton, VIC

- ✓ Future climate impact without perennial innovation: a 15% reduction in whole-farm farm profit without perennial pasture and mallee innovation;
- ✓ When the Triple pasture system plus mallees were introduced at the whole-farm level income was raised back to the historical levels, and these improvements were adopted on a substantial part of the farm;
- ✓ At the paddock level the AEV of Merino wool and meat enterprises would be severely reduced without adaptation, and income variability would be very high due to supplementary feeding costs in drought years;
- ✓ Even with the improved perennial pasture system (Triple) there is a substantial reduction in farm income and income variability remains very high;
- ✓ When crops were tested at the paddock level the effect of a changed climate without adaptation is for a substantial reduction in paddock income, but not to the levels of the base pasture and livestock enterprise. Therefore, adoption of cropping with a rotation of cereals and break crops may be a profitable strategic adaptation to future climate.

3. Contemporary climate change issues for Australian agriculture and context for this project

Summary

In this chapter we review recent Australian literature to set the scene for this project. As suggested in that literature, the project undertakes a farming systems approach using a multi-disciplinary analysis of new agricultural adaption options for a changed climate. It builds on an existing biophysical research base for perennial plants and mallee for tree biomass. This enables us to make an economic assessment of the incentives to adapt in a climate changed world.

3.1 Purpose

In this chapter we develop the context for this project using a review of literature relating to climate change as it is expected to impact on four prominent agricultural regions of Australia.

Contemporary thinking about research and policy has emphasized the need to investigate both mitigation and adaptation options for landholders in pursuing individual and societal objectives for the future state of agriculture in Australia. This project investigates adaption options for dryland farming systems in southern Australia. This project extends work already being undertaken by the FFI CRC to systematically research perennial plants as a management adaptation option for Australian dryland agriculture in a changed climate future (FFI CRC(2012)).

3.2 The need for research

Rickards et al. (2012) surveyed recent literature in the context of reviewing the NARP for primary industries. The primary industries NARP is concerned with identifying priority research questions for primary industries climate change adaptation. There is a need to provide guidance for decision makers facing complex issues and options for adaptation in primary industries (Rickards et al. (2012)).

At the Australian Government level, a priority for research into greenhouse gas emission reductions for agriculture is to provide options for land managers which reduce emissions, while simultaneously boosting their productivity and profitability (Department of Agriculture, Fisheries and Forestry (DAFF) (2012)).

Both these sources emphasise the need to identify and evaluate adaptation options and provide information for decision makers facing an uncertain future.

3.3 A framework for research

Rickards et al. (2012) referred to a framework for conceptualizing adaptation options in primary industries which distinguishes between:

1. Incremental or adjustment;
2. Systems level; and
3. Transformational adaptation.

They commented on the first of these by noting that ‘an important, if limited, area of research relates to understanding the costs and benefits of incremental or adjustment level change adaptation options, both for avoiding damage and for gaining benefits from climate change’ (Rickards et al. (2012), p.8).

With respect to the second of these, Hayman et al. (2012) considered climate change through the farming systems lens because they considered this to be the level at which many of the impacts of a changing climate will be felt. Questions asked by those managing farming systems can be categorized under four broad headings:

1. Climate projections at a local scale;
2. Impacts of climate projections on existing farming systems;
3. Adaptation options; and
4. Risks and opportunities from policies to reduce emissions.

Hayman et al. (2012) acknowledged the complex balance in on-farm strategies between adapting to climate change and reducing greenhouse gas concentrations.

Rickards et al. (2012) also discussed the farm systems level as the scale at which many adaptation needs and opportunities will be expressed. Changing primary production systems could mean introducing novel but relatively well known or understood production types to producers or regions. This type of change normally involves greater risks than incremental or adjustment level changes.

3.4 Existing farm management processes and adaptive capacity

In their review, Rickards et al. (2012) referred to the need to focus on adaptive capacity of decision makers, the ‘context-specific character of climate change impacts and, in particular, the local specificity of potential and actual responses’. Approaches to understanding adaptive capacity have broadly consisted of a ‘top down approach’ emphasizing forms of human capital that jointly represent the resources an individual or group may have at their disposal to manage change and derive a livelihood, and a ‘bottom up approach’ which conceives adaptation as a dynamic, subjective context-dependent and multidisciplinary approach. They found very few studies explicitly and comprehensively examine the adaptive capacity of Australian primary producers. However, Nelson et al. (2007) used rural livelihoods analysis as a conceptual framework to construct a composite index to provide policy-relevant insights into the constraints and options for building adaptive capacity in rural communities.

Innovative Australian farmers have always adapted to changed circumstances. Asseng and Pannell (2012) considered adapting dryland agriculture to climate change for Western Australia. They found twentieth century changes in rainfall, temperature and atmospheric CO_2 concentration have had little or no overall impact on wheat yields. Changes in agricultural technology and farming systems have had much larger impacts. These authors consider that ‘there is no scientific or economic justification for any immediate actions by farmers to adapt to long-term climate change in the Western Australian wheat belt, beyond normal responses to short-term variations in weather’.

For Australian farmers already adapting to changed circumstances the question is whether they can continue to adapt autonomously to future changes. Pannell (Undated) considers that the ongoing decline in public investment in agricultural research will have far worse consequences for agriculture.

3.5 Options for adaptation

Howden and O'Leary (1997) evaluated options to reduce greenhouse gas emissions from wheat cropping systems of the Wimmera region of Victoria. This objective could be achieved by choosing stubble retention systems, which can increase the wheat yield substantially compared to conventional-till continuous wheat. This capability may be enhanced by tactical management decisions that change fertilizer inputs depending on soil moisture levels at sowing and on seasonal forecasts.

Kingwell (2006) reviewed the adaptive capacity of the Australian agricultural sector to climate change and found that options with most potential were extensions or enhancements of existing activities for managing current climate variability. In broadacre farming a range of coping and adaptation options includes:

5. Development of more robust crop and pasture varieties adapted to greater weather-year variation and changes in adverse conditions expected from climate change;
6. Staggered planting times, erosion control infrastructure, minimum soil disturbance crop establishment, crop residue retention, resilient varieties;
7. Improvement in weather forecasting skills to aid crop operations such as seeding, spraying, swathing and harvesting);
8. Further facilitation of decisions about stocking and de-stocking through improved climate prediction systems this includes alteration of mating time or mating populations based on seasonal conditions and forecasts;
9. Assessment of genetic variation across and within livestock breeds regarding their production response to extreme heat, so that more productive animal systems can be developed;
10. Re-design of farm housing, building, machinery and outdoor clothing to accommodate extreme heat; and
11. Development of profitable crops or tree species that include returns as renewable energy or carbon sinks.

Kingwell's (2006) review highlighted research which showed that if broadacre farms were reliant solely on current technologies and enterprise options then as the climate became warmer and drier, optimal farm plans on all farm types considered became characterized by:

1. Markedly less profit;
2. Greater areas devoted to pasture and less to crop;
3. Less tactical alterations of crop and pasture areas from year to year;

4. Reduced numbers of sheep, lower stocking rates and more supplementary grain feeding per head; and

5. Slightly more area allocated to perennial plants (lucerne, saltland pastures and oil mallee).

In another study reviewed by Kingwell (2006), even in the absence of new technologies and enterprise options, farmers would adjust and adapt to climate change by altering their existing mix of enterprises, changing rotations across soil classes, altering stocking rates, and changing feeding regimes and livestock flock structures. However, in spite of these profit-enhancing adjustments, farm profitability in the study region was projected to decline by up to 50 per cent or more in worse-case scenarios, compared to historical climate. The main factor influencing this decline in farm profit was the decrease in crop production as a result of declining crop yields given the increased frequency of dry weather years and the reduced frequency of very favorable weather years that reduced the contribution to expected farm profit from tactical alterations in the enterprise mix in these favourable years. This analysis revealed the substantial size of the technical and financial challenge posed by possible climate change for the study region which was already subject to low annual rainfall and bordered the margin of cropping in south-west Australia. However, if the rate of climate change is slow enough then crop varietal development and agronomic and management innovation will cushion adjustment costs and reduce the projected decline in farm profit.

One other finding of John et al. (2005), as reported in Kingwell (2006), was that adverse climate change is projected to reduce the financial capacity for adoption due to reductions in financial liquidity. Hence, expensive, lumpy capital investments (e.g. cropping gear, additional farmland) may be difficult to undertake, especially as these investments are often conditional on periods of favourable seasons. The reduced frequency of these seasons could inhibit some capital replacement or expansion decisions of farmers.

Where climate change is not rapid, farmers' traditional responses to climate variability in broadacre farming in Australia are likely to facilitate their effective adaptation to climate change. This is because accompanying and underlying climate change will be the continued stochasticity of weather-year variation. It is this variation that typifies the environment of much of Australian agriculture and occupies the minds and talents of many farmers on an annual basis. Although climate change will lead to the eventual alteration in the frequencies of weather-year types, it is farmers' abilities to respond to climate variation, rather than climate change per se, that is likely to serve them best in the short and medium term. Already Australian broadacre farmers display abilities to successfully respond to existing climate variation (Kingwell 2006).

Hayman et al. (2007) compared climate knowledge with other on-farm innovations. Improved climate knowledge or information '.. can be applied across the whole farm (economies of scale) and across a range of decisions and enterprises (economies of scope)'. They go on to say that using such information '.. requires clear thinking on how to incorporate imperfect information into planning; this clarity of thinking, if translated into practical risk management, is likely to have significant payoffs'.

An important point in the context of Australian agriculture is that options to reduce emissions or adapt to changing circumstances need to have productivity and profitability benefits.

Keating and Carberry (2010) considered emerging opportunities and challenges in Australian agriculture, including new products or services from agriculture such as biofuels, forest-based carbon storage in agricultural landscapes, bio-sequestration of carbon in agricultural soils, and environmental stewardship schemes that would reward farmers for nature conservation and related non-production services from farming land. Their overall conclusion was that none of these on their own will transform the nature of Australian agriculture. Instead the greatest emerging opportunity for Australian agriculture must be sought from productivity breakthroughs in the face of current and emerging constraints.

Potgieter et al. (2012) investigated the spatial impact of projected changes in rainfall and temperature on wheat yields in Australia. They estimated yield changes assuming no adaptation with and without CO_2 fertilisation effects. The 2020 yield projections showed negligible changes in the modeled yield relative to baseline climate. For the 2050 high emissions scenario, changes in modeled yield relative to the baseline ranged from -5% to +6% across most of Western Australia, parts of Victoria and southern NSW, and from -5 to -30% in northern NSW, Queensland and the drier environments of Victoria, South Australia and inland Western Australia. Taking into account CO_2 fertilisation effects across a north-south transect through eastern Australia cancelled most of the yield reductions associated with increased temperatures and reduced rainfall by 2020, and attenuated the expected yield reductions by 2050.

Research conducted by the FFI CRC (2012) is developing new and innovative farming systems and technologies to improve the resilience of Australian broadacre agriculture to climate change, salinity, climate variability and drought while improving productivity and sustainability. The FFI CRC has primarily focused on the use of perennial plants, due to their ability to cope with declining and variable rainfall. Deep roots of perennial plants enable them to capture and effectively use water at depth when there is little rainfall. Furthermore, these plants, particularly the woody perennials such as mallee grown as energy crops, can remove excess water in times of plenty, which could otherwise contribute to salinity by recharging groundwater during wetter periods (Mendham et al. (2012)).

One of the new plants developed by the FFI CRC is Tedera (*Bituminaria bituminosa* C.H. Stirt var. *albomarginata*). Tedera is a drought tolerant perennial legume originating in the Canary Islands. Finlayson et al. (2012a) evaluated the potential role and value of Tedera in dryland mixed crop and sheep livestock production systems in southern Australia. The analysis considered the quantity and quality of feed produced on meat versus wool-producing sheep flocks and used a whole-farm modelling approach to assess the potential to increase farm profits in these systems.

3.6 Transformational change

The third type of adaptation discussed by Rickards e t al. (2012) was transformational adaptation, which they considered to be an ambiguous and contested topic. Characteristics of transformational adaptation tend to be defined in terms of scale, but a very wide range of adaptive actions have been described as ‘transformational’ and several classifications of transformational change have been proposed. Examples of transformational change that have been outlined in the literature include:

- Introducing a new activity to a region or resource system that has not been previously experienced or exposed to it; and

- Changes to land use (such as expanding or contracting agricultural activities in response to climate change).

The land sectors will be greatly affected both by climate change and its mitigation. Science-based (and other sources of) knowledge and flexibility of production systems will be the keys to success in this new world, as they have been throughout the history of Australian farming. The rural sector is a major source of emissions, but at the same time holds tremendous opportunities to play a significant role in Australia‘s mitigation effort. These opportunities could also significantly improve the economic prospects for Australian farmers (Garnaut 2011).

Producing biomass for bioenergy is a case of the first of these examples. The use of planted mallee eucalypts as a biomass source for energy and other products has been investigated for a number of years, and has been demonstrated in a pilot bioenergy plant in Western Australia. Unlike some agricultural sources of biofuels, the ratio of energy output in biomass to energy inputs in production is highly positive (Wu et al. (2008)). Commercial viability of growing mallees for bioenergy would be enhanced by innovation to reduce growing, harvesting and transport costs. Cost reductions of 50 per cent are anticipated within ten years. Bioenergy production could also use a combination of biomass sources (e.g. cereal straw or downgraded hay). Subject to constraints bioenergy production can improve on mitigation benefits of forests grown only for carbon sequestration. A CSIRO study found that the combined mitigation from carbon sequestration (allowing for losses from harvesting) and bioenergy production from a short-rotation plantation could be three times that of an unharvested forest covering the same areas. These combined mitigation benefits could allow for productive land use in regions where declining rainfall has made crop production less profitable or uneconomic. Use of low profitability land (e.g. deep infertile sandy soils consigned to low productivity pastures) for biomass production would improve farm profitability, reduce impact on grain production and could provide a new source of regional income where biomass processing and biofuels manufacturing may take place (Garnaut 2011).

Keating and Carberry (2010) reviewed new products or services from agriculture such as biofuels, forest-based carbon storage in agricultural landscapes, bio-sequestration of carbon in agricultural soils, and environmental stewardship schemes that would reward farmers for nature conservation and related non-production services from farming land.

3.7 Trees for biomass

FFICRC also has a dedicated program for the development of woody crops for rainfed farming systems. Mallee eucalypts are being developed with the aim of offering growers the option of a profitable tree crop that grows biomass for feedstock in the production of energy and fuel. As part of this development some 14 000 ha have been established across the WA wheatbelt since the early 1990s. This development aims to use profitable woody crops as the vehicle to also achieve important environmental improvements within the present agricultural system. These improvements include reductions in greenhouse gas emissions, managing recharge of excess rainfall that contributes to dryland salinity; provision of shade, shelter, amenity, and erosion control; achievement of better protection of biodiversity both on and off the farms; and as means of production of a carbon neutral fuel with potential for carbon sequestration in its roots ((Yu et al. (2009), Bartle and Abadi (2010)).

There is substantial interest in biomass as a renewable energy source to address issues of global climate change. For agriculture energy is a major input cost but it can also be an output in terms of bioenergy feedstuffs (Bartle and Abadi 2010). But bioenergy produced on farms must be financially competitive as an enterprise compared to existing agricultural production.

To be competitive bioenergy requires development of second-generation (lignocellulosic) rather than first-generation (starch, sugar, and oilseed) feedstuffs (Bartle and Abadi 2010). Woody crops are a source of second-generation feedstocks which have the potential to complement intensive agriculture and reduce its environmental impact (Bartle and Abadi 2010). If there are reduced environmental costs associated with woody biomass crops then these crops may have a lower effective cost than otherwise perceived.

The technical and economic feasibility of woody biomass crops is an important area of research. Stucley et al. (2012)undertook a case study of mallee eucalypts developed for use as a woody crop with biomass harvests taken on a 4-year cycle. On a farm the trees would be planted as narrow belts of mallees, widely spaced within existing agricultural; systems that involve sequences of rainfed crops and pastures. These are often called alley farming systems.

The studies of Peck et al. (2012), Mendham et al. (2012) and Stucley et al. (2012)build on two decades of development of native mallee species as short-cycle woody crops in the south-west of Western Australia. The alley-farming layout provides a large tree/agriculture interface, enabling the tree belts to provide benefits to and capture surplus resources from the adjacent crop/pasture land. Abadi et al. (2013) undertook detailed economic modelling of the biomass production system and supply chain, and developed estimates for the potential value of the associated benefits (or co-benefits) of integrated mallee/annual crop systems. These co-benefits include reduction of water logging and groundwater recharge; shelter and protection for crops, livestock and soils; and protection of biodiversity assets and infrastructure. Belts of mallees in farm land also impose competition on the immediately adjacent agriculture and this competition zone is accounted for in the analysis. For a review of shelter belts in Australia see Cleugh et al. (2002).

Mallees also provide biodiversity benefits. For example, they provide supplementary food and shelter resources for some wildlife, e.g. the Western Pygmy Possum (Short et al. (2009)). Recent work in the WA wheatbelt that has indicated that oil mallee farming systems can have substantial habitat values (Prober and Smith 2009).

3.8 Implications for this project

This project draws on themes and imperatives developed in the above literature.

The project takes a farming systems approach to analysing potential adaptation to climate change using new perennial plants and mallee trees for biomass assessed for existing systems. It investigates the incentives for landholders to adapt and change using these new options. The project incorporates a spatial aspect by evaluating these options for dryland agriculture at four locations in southern Australia.

The project is multi disciplinary (including climate, plant biophysical and economic analysts), but as Nelson et al. (2007) have shown other aspects of adaptive capacity can be developed. The analysis involved climate series being downscaled for each location and checked for suitability. Biophysical modeling of plant responses to the historic and future climate series was undertaken to develop distributions of crop yields and seasonal patterns of pasture plant production. These plant parameters were used in economic models to assess potential productivity and profitability changes.

The project addressed adaptive capacity in terms of potential economic incentives for change. For innovative farmers the question is not necessarily about their adaptive capacity, but rather the benefits and costs of the new technologies in a farming systems context. This is another way of addressing adaptability; by considering the technology or change itself in terms of its appeal to decision makers. We assessed existing farmer objectives and attitudes to change by interviewing a small number of farmers and agricultural consultants at each project location.

The project includes detailed farm economic modelling to assess the systems implications of changing to perennials and mallees for biomass in a climate changed world, and also addresses the issue of risk associated with these technologies.

4. Consultations at project sites

Summary

A small survey was conducted of farmers/graziers, agricultural consultants, and agricultural researchers at the commencement of the project. The objectives were to find out about existing farming systems in each project location, to discuss the feelings of respondents about predicted climate change and find out how they might react, and to canvass their responses to a potential on-farm tree activity (growing mallee biomass for biofuels production). The process involved a free-format discussion of these general questions conducted on farm properties, at universities or at research stations. The discussion was recorded by note taking which is transcribed (with minor edits) in this chapter. The main responses to the stated objectives are derived from a general reading of this transcription.

These farmers and consultants know their local conditions and environments, so that they have developed their farming systems to suit their own objectives. Even for this small number of respondents there are differences (larger or smaller) between adapted farming systems within the same region or district. We need to remember this and be careful in interpreting the results of our farming systems analyses.

The farmers showed that their management is attuned, and responsive, to environmental variability. This is exhibited in their strategic and tactical management responses.

With respect to predicted climate change they were generally confident that they could adapt (at least in the shorter term) to changes in the distribution of temperature and rainfall. Given their knowledge and experience, they were looking for new technologies (sometimes expressed as plant varietal improvements and other technologies) to help them in the adaptation process. They are used to reacting to climate variability in managing their farm businesses.

In terms of their personal objectives, although they were interested in environmental outcomes (a number had planted trees and were involved with LandCare) their main motivation was primarily economic. Their quality of life depended on the economic outcomes from their farm businesses. Some of them strongly felt that they were ‘feeding and clothing the world’.

This motivation was confirmed when asked about mallee as a biomass crop grown in alley farming systems. ‘Show me the money’ was an underlying response to this possibility – they were not averse to a new farming activity or concept, despite the lack of an existing market or industry. They were willing to be innovative and adapt to taking on new opportunities and change the way they do things in response to a changed environment. This survey has provided interesting and valuable background to the project.

4.1 Farm visits

4.1.1 Purpose

This chapter reports on visits at the start by the project leaders to the four project locations to hold discussions with farmers and agricultural consultants.

The objectives of these visits were to: (1) observe and understand the farming systems in each region/location; (2) talk to farmers, agricultural consultants and scientists about climate change issues and how they are responding to this; and (3) ask specific questions about a potential on-farm activity of growing mallee trees for biomass production, which would be implemented through an alley farming system.

The rest of this chapter is a narrative of the discussions with each respondent, on which the later project discussions will draw.

4.2 Great Southern Region of WA (Katanning)

The first farmer interviewed was located at Katanning and we visited the farm and were given a brief tour. As background the annual rainfall records for the farm show for 1890 – 1900, 370 mm average; for 1900 – 2000, 460-470 mm average; for 2000 – 2010, 370 mm average; for 1960 – 1980, 460 mm average; and for the last 15 years drier, with 200 mm in 2010 but 700 mm in 2011.

The farm has 96% financial equity. There is a particular system of contour drains with trees growing in the bank (fenced for stock) for water collection and use.

The normal crop rotation is canola-barley-canola-barley–pasture (4 years), with overall 30% of area cropped (stubble grazed). Clover is resown in the pasture phase (red-legged earth mites are a problem). He applies superphosphate in 1st year of pasture and doesn't have to worry about weed control. The pasture stocking rate is 11—11.5 Dry Sheep Equivalents (DSE)/ha in winter, a little lower in the first two years of pasture. The district system and rotation is quite similar (except for the contour drains).

Recent climate trends have been drier in winter and wetter in summer. Therefore he is interested in more perennials (especially lucerne), but has no thought of summer cropping.

His livestock enterprises revolve around Merino ewes which are mated to either Merino rams or Poll Dorset rams producing first cross lambs. Lambs are normally born May/June but there is interest in later lambs (born Aug/Sept).

Discussion points included that lucerne would have the advantage of being tolerant to low rainfall in summer; he is interested in rotational grazing, or feedlotting with hay/grain; normally the season break (Mediterranean climate) is 10 May (range 20 April to 10 June), but he is observing later starts to the season. This is good for crops with less waterlogging of soil.

With respect to potential changes (new ideas) for his farm he has found that perennial ryegrass doesn't persist in that area; he is adaptable but would need a lot of convincing to go to summer crops (issues of soils, water, equipment and markets); for him, alternative perennials could be millet to feed sheep, or lucerne to rotate the pasture; the price of meat is an incentive to maintain the livestock enterprises; he has tried tagasaste. For mallee or tagasaste he would expect to plant in plantations and graze/coppice, but there are issues of weeds and insects in establishment.

His responses to particular questions were:

- If rainfall reduced to 370 mm what would change?

- Depends on the perennial's requirements for rainfall?

- Are Mallees on your radar?

  - Is there a CO_2 sequestering benefit? Farmers have very low understanding of the details. Not very interested for his farm. How economic? Could do better further east;

- Is alley farming of mallee with coppicing an interested proposition?

  - Possibly for areas further east;

  - 'It's all about the $/ha', 'no biomass industry established yet';

  - A chicken and egg problem, need a biomass plant and harvesters, also depends on the landscape of the farm (he has reasonable elevation and not much of a salt problem), for his farm (layout) he doesn't really want more trees;

- For mallee would he require a premium over an average return/ha of, say, $130?

  - More of a mindset for farmers wanting to just grow crops without any impediment, i.e. pastures are a hindrance to some farmers.

- A last comment is that the CSIRO did a trial of Lucerne on his farm. On his soils he can accept 50mm more rain because the lucerne dries out the soils. Therefore it increases water use by 50 mm.

The second farmer interviewed was from Cranbrook, 100 km north of Albany and south of Katanning. His farm has sedimentary saline soils of the north Stirling Basin, shallow duplex soils (with shallow groundwater to 0.5m), and naturally suited to shallow-rooted plants. His property is low in the landscape, susceptible to frost and therefore he doesn't grow wheat or barley. His farming system is basically 30% crop and 70% Merino sheep. His average rainfall is 450 mm and he thinks it is getting wetter. There may be a slight increase in temperature which may increase pasture growth rates. However, there may be some issues with the break of season (becoming less intense), perennials can help with this.

The main rotation is canola-oats-canola-annual pasture (2-4 years). The crop choice depends on a seasonal forecast, in drier years he takes areas out of crops to have enough feed for sheep. Some of the oats are grazed. He runs a reasonably high stocking rate of 8-10 DSE/ha in winter and has a 'fluid' decision making process (i.e. if no rain by 24 May he drops paddocks out of crop).

He has been growing perennials for a long time – kikuyu on deep sands and old man saltbush on the duplex (waterlogged) areas. His father ran an annual-based system until 1963; there was a natural salt problem and decided to improve the poorer land with clover/ryegrass dominant pastures (after reading an article by Clive Malcolm of CLIMA). He used EM38 surveys to target areas for saltbush.

The saltland pasture system involves atriplex saltbush, tall wheat grass, puccinellia, balansa clover, lotus, and tedera. He feels that he is missing a legume in the saltland system.

His stocking rate is 8-10 DSE/ha on both poor and better pastures. He uses rotational grazing, with the perennials extending the summer pasture through to December or January.

He has used perennial pastures for 10 years; 33% of the non-cropped land is under perennial pastures. He is not a great believer in perennials on good land, but there might be a reason to use them, e.g. plant lucerne to stop recharge.

In his opinion many farmers are already adapting to climate variability, all doing zero tillage and stubble retention (farming like the wheat belt farmers), 'Australian farmers are adapting to a changed climate'.

Crop yields: autumn canola 1.8 – 2 t/ha, although 2010 was a terrible yield year (1.4 – 1.5 t/ha), oats yield 2.5 – 3 t/ha (in 2010 was 1 t/ha).

Crop inputs: for canola compound fertilizer (N, P, S, K), Triumph 100 kg/ha at sowing (May) + 50 kg/ha urea topdressed in July and 100 kg/ha sulphate of ammonia topdressed in August; oats same as above without sulphate of ammonia. Normal weed control for oats is a knockdown of Dual Gold and Triuron.

We asked him about mallee in an alley system. He would be interested if there is a financial benefit, but he is dubious about carbon farming, doesn't want to lock something up for 100 years. In terms of production benefits there is sheep shelter and there may be other production benefits. He sees himself as producing food for the world, 'I feed 80 other people in the world'. He would not countenance a caveat on his land title.

His shire (Cranbrook) has lignite coal and forestry, but is low in energy. Therefore bio-fuels for power generation would be welcome. Bluegums have ruined the reputation of trees in Shires (left a stigma); no money comes into the region.

He commented on the heterogeneity of landscapes, alley farming could be OK but he is interested in big blocks for ease of management and efficiency. Alleys could fit well in large farm areas. If perennials had productivity benefits for the poorer (salty) areas then that would be an advantage (these areas not producing much anyway).

Graziers utilize straw, but for croppers straw is a problem. Lots of people are going into cropping (in a big way).

The first consultant that we spoke to operated around Katanning. He characterised farm decisions as long-term (e.g. property acquisition) and short-term, with the latter often not changing very much. With respect to climate change, farmers won't change until they see a need. For instance canola adoption was very quick because sheep prices fell. Three important issues for any farm changes are (1) a clear need for cash flow; (2) farmers need to understand the principles; and (3) the need for practical technologies. Rotation change in the Central Wheat Belt occurred very quickly.

Regarding perennials, there was a push several years ago but adoption was low because the LandCare source didn't understand the farmer perspective, there was no economic case and there was a large change required. Now some farmers have tested and adopted perennials, they have a niche on salt-affected land. Kikuyu and tall wheat grass are idiot proof, but lucerne has been terrible. On lighter (sandy) soils kikuyu is most robust, especially on lower slopes (wet and/or saline), but performance on mid slopes (better soils) is not known. The performance of phalaris and tall fescue is unresolved in his mind. Another important issue is that for any land that is potentially croppable, farmers don't want to close off the options for 3-4 years. In terms of salinity, if there is not an immediate risk then people won't make a change.

Regarding climate change, his comments were that it is a long time into the future and not much that they can do about it. He is doubtful of the forecasts. It won't change the core program. Farmers are happy to make small changes in the short term but can't make changes to a long-term rotation. In terms of cropping, weed control determines the rotation, with nutrition being a lesser problem (paddocks get tired because of weeds and nutrition). 'At the end of the day nothing has changed, scale is where the money is'.

For climate change, businesses have short to medium term cash flow incentives which restrict change. What might change are the big decisions about land purchase.

Issues for croppers are to keep control of weeds (radish and ryegrass), and herbicide resistance is a problem. With respect to uptake of new technologies, farmers need to see real value from a change. The problem for perennials is that there is not enough information; the economic case for perennials hasn't really been made.

For strategic use of perennials to finish fat lambs, the potential improvements from perennials were small beer. Canola was a large change.

It is possible to influence stocking rate and the volume of product sold through changed lambing time. But the change in supplementary feeding is small beer. Need a large change, e.g. 7 to 10 DSE/ha. Introducing perennials into a farming system would be a big change, therefore need a large economic benefit – changing supplementary feeding is a small payoff, changing the stocking rate is a larger payoff. Any change would need an effective extension message. In his experience any change to time of lambing was only successful with one-on-one regular contact (consultant and farmer). If there is a complicated systems change then that needs to be sold for change to occur.

When questioned about how he would help his clients in a climate changed world, he commented that the predicted changes aren't enough to make change required or be important. With respect to perennials there would need to be very strong evidence for people to change from crops to perennials.

When asked about mallee for biofuels in a coppicing system he said: that there is a need for certainty (no processing plant at present), the Bluegums experience has done the forestry industry a great disservice. Any medium to long term commitment would be only for paddocks with no cropping potential. Farmers would doubt how long it would last, they know what works (wheat, sheep), but it could be a possibility in salt-affected areas. Farmers would want to see the plant and see the business model working. Five years is a long time in contractual terms, trees are a very different business model, need to align with a new business partner. Farmers have a short-term planning horizon because of the variability of seasons, there would be special problems if farmers don't understand the new system and don't see a clear need. Canola responded to a big need; it was a simple product, there was a recipe approach and there was a large payoff.

4.3 Central Wheat Belt Region of WA (Cunderdin/Kelleberrin)

The third farmer was located north of Kelleberrin in the central Wheat belt. His property is 2000 ha with crop and livestock rotations. He is interested in trees on farms and has actively encouraged tree corridors linking bush land areas. He earns 70% of income from cropping and 30% from sheep; costs are lower for sheep.

Livestock are Merino ewes mated to either Doonie Merino (75%) or terminal sire (25%) rams such as South Suffolk. Pastures carry 2-3 sheep/acre (4-5 DSE/ha) but he may adjust down to avoid being overstocked. There is no permanent pasture because wheat makes more money, and there is generally only 1 year of pasture (sub-clover) or 2 years as a paddock cleaning exercise. The meat sheep enterprise can make money, depending on the price of wheat.

He has flexible crop sequences, some portions are continuous cropping with barley, if weeds become an issue he can sow clover or lucerne. The crop rotations can be wheat-barley-wheat-lupin, or wheat-wheat-barley-barley-lupin, or wheat-wheat-wheat-barley; these are on the parts of the farm where continuous cropping can be conducted. On other parts he uses sub-clover-wheat-SC-wheat, but the pasture components suffer from establishment problems due to the variable season break. He also uses bioserula (BSR) in rotation with wheat. The cost to sow lucerne is the same as pasture legumes. Lupins generally only yield 1 t/ha so can't make money from this.

Wheat yields were 2.5 t/ha in 2011 (average 1.8-2 t/ha over last 19 years), and lupins yielded 1.5 t/ha in 2011 (0.8 t/ha over last 10 years). The 2nd year of wheat generally yields lower. Nitrogen fertiliser used is 30-40 kg N/ha (rule of thumb) on top of what is already in the soil. If wheat establishment is good and the season promising then he will apply more N; i.e. a split application of 6-8 units of N/ha at seeding (+ 10 units of P) and then add more granular post emergent by the end of July after tillering (2-3 tiller stage), and then more liquid flexi-N if needed in better years.

Soils are 40% duplex sandy loams over clay (20 cm loam & 80 cm clay), 40% loamy Jam country (indicator vegetation is York Gum, Sawkins (2009)) and 20% sand plain. The duplex sandy loams can get waterlogged occasionally (in July). The JAM soils are deeper red loams including granite. These areas are undulating and have less moisture. The gravelly sand country is best for long rotations.

Farm income is higher from wheat than sheep, but with more risk.

When asked about the possibility of including perennials (clover, lucerne) he indicated that lucerne would be advantageous for the water table issues. He doesn't aim to be a grazing venture relying on lucerne; the grazing value is not there in his climate. Lucerne can be utilized when fresh water is close to the surface (i.e. in particular paddocks), but if there is no summer rain then there is no benefit from lucerne as a source of summer feed. He uses lucerne not for its grazing value but to clean up areas in the broad valley floors.

Tedera is only good for someone growing sheep, and there are not enough people growing sheep any more. People (young farmers) will never go back into sheep, they have pulled out fences, there have been 10 years of low prices and they can't buy back in now because of high sheep prices (the capital investment). Young people prefer to drive tractors and go away on holidays (lifestyle factors), as well as the fact that the pure economics are against it (see above). The BankWest benchmarking figures don't tell the whole story.

When asked about mallee for biomass, he said that he has some mallee and neighbors do too. If he can get paid for biomass then he would go for it. Farmers will adopt things quickly if there is a return. He has already planted a lot of trees with LandCare without a financial return. There is no reason why mallees can't be successful if the system can be sorted out. However, he had doubts about the system if there is contour farming, most people want an up-and-back or straight-line system. Couldn't do with steep contour banks but could be OK with broad flat banks. People are getting rid of contour banks so they can crop more efficiently, there is less runoff now. Farmers are going more into straight lines with controlled traffic, long efficient runs in a straight line are essential.

With respect to a required rate of return, he would be looking for the same return as cropping but would want other environmental benefits. The returns would need to be fairly substantial, partly because of the infrastructure needs to get machinery and product on and off the farm. Existing infrastructure for the wheat industry is substantial, there is on-farm storage and off-farm there are roads, receival facilities, storage and rail. So a new industry would need more than marginal increases in returns and infrastructure investment for people to change. However, if mallees were only 5-7% of the land area then the required rate of return would be lower. He is attracted to the idea, but it would have to fit into the wheat growing system. He is not averse to changing to an energy crop.

When asked about climate change, he said that this is a wheat and sheep area and this won't change quickly because of the existing infrastructure. He is concerned about services declining in local communities.

The fourth farmer was located very close to the previous farm, a younger farmer with a young family. His soils are very similar to the previous farm, but with deeper sands (Tamar yellow clay soils) and very acidic. He chooses rotations for soil types, mainly wheat and lupins. He has 45% sandplain, 30% duplex and 25% red sandy Jam country.

On sandplain country the rotation is lupin-wheat-wheat-canola-wheat-lupin. This is better quality soil with higher yields (lupin 1.1 t/ha, $wheat_1$ 2.5 t/ha, $wheat_2$ 2.2 t/ha, canola 1.1 t/ha, $wheat_3$ 2.2 t/ha). Fertiliser applications are lupins P: 8 kg P/ha, wheat N: 50 kg/ha urea + 8 kg compound N = 32-34 kg N/ha (split between seeding and mid July), and canola: 50 kg N/ha, 8 kg P/ha.

On duplex country wheat yields are 20% less than sandplain and can't grow Lupins. The rotation is pasture-wheat-wheat-canola-wheat. The pastures are ideally sown legumes (Seredella and clover) to give rotational benefits.

On Jam (rockier) country the rotation is pasture-wheat-pasture, with the pastures being Dalkieth sub clover. Pasture stocking rates are 4 DSE/ha with rotational grazing being practiced. The sheep graze May to November on pastures then on stubble. The wheat yield is 20% less than on sandplain (1.8 t/ha). Pasture stocking rates are 4.5 DSE/ha and the ratio of crop to livestock income is 85:15.

When asked about perennial pasture he responded that 4-5 years ago he tried lucerne for 3 years (lucerne-lucerne-lucerne-barley) to dry out wetter parts. The lucerne survived but was very uneconomic. He couldn't graze many sheep; it didn't grow very well in winter and only grew well in 1 of 3 years in summer.

When asked if there were any perennial pastures on his horizon he referred to a summer legume trial run by Elders, a legume to replace Lupins or grow on shallow duplex soils to provide N for Wheat. The need was for summer rain, i.e. only opportunistic.

When asked if he had any waterlogging problems in winter, he replied that there was not much need. Conservation farming of cropping has meant that there is less runoff and less need for contour farming (he has pushed out most contours, only left the ones running into dams). Conservation farming has meant that they can get crops up even in very dry years (i.e. by the end of May).

When asked about alley farming and biomass production, he said that he would consider it (he has lots of room for trees) but it would need to work in with the cropping auto-steer machinery. Need square paddocks and accommodate a 120' boomspray.

He stated that the biomass production would be on 5% of the farm. He does get some wind erosion in the Lupin phase when sheep graze the stubble.

When asked about how much benefit he would require to change, he already has rows of trees from LandCare mainly for water control. The competition effect would be very little on sandplain country. He stated that he would only do mallees for biomass/energy purposes, not for water retention purposes.

When asked about the issue of permanence, i.e. the idea of covenanting land for carbon retention over a long period, he said this would be an issue because it would close options for other technology changes. He would need a very high premium over the existing system.

4.4 Southern Riverina Region of NSW (Tarcutta/Wagga Wagga)

The fifth farmer was located at Tarcutta close to the FFI CRC EverGraze® field site. He is also involved (full time) in regional agricultural extension and is well aware of plant modelling with GrassGro and development of regional gross margin budgets. His farm size is 880 ha with 20 paddocks (60% arable). Soils are red loam and grey sodic, the former being arable. Annual pasture species are annual ryegrass and sub-clover, and he also has lucerne. Originally his farm was all livestock (sheep), but now he includes cropping to spread the risk and to give more management flexibility. But livestock require more labour. Grain prices vary more within a season than livestock prices.

Typical rotations are canola-wheat-wheat-canola or barley-lucerne (3-4 years), or canola-wheat-canola-wheat. The choice also depends on relative commodity prices. Livestock enterprises take a lot of labour, and he gets a contractor to sow and harvest crops. A rotation depends on how long the farmer wants to crop.

The EverCrop® survey results (west of Wagga) showed that perennial pastures have Annuals in them, but this is a transition from drought. Important crop weeds are annual ryegrass, capeweed and barley grass.

Locally there are a lot of annual pastures in the farming systems, but more lucerne recently. Hard seeded clovers are common. In non-arable areas pastures can be sown, but clovers have gone out due to poor seasons (drought and false season breaks).

When asked his thoughts about mallees as a potential farm activity he was cautious about the surety of payment (what if markets fail?) and also concerned about the aesthetics after harvest. He was not sure whether the local farm sizes were big enough. Farmers can already sow trees for money, but will trees of this sort disrupt the farm? Ten percent of his farm is already in trees, but mostly planted in rocky areas. His comment was that mallees would require significant other benefits (environmental) than profits, in case it fails.

The sixth farmer was located nearby and farm size was 1000 ha. Over 60% of the area was red brown earth on top of slopes (pH 4.9-5) with 30% being yellow podzols in valleys (pH 4.5). The podzol soils are acid on top with alkaline clays down to 1m depth.

With respect to crop rotations the restriction is slope. Of his farm 25% is non-arable and 75% arable (33% yellow podzols and 67% red-brown earths).

Wheat yields on yellow podzols (if limed) 7 t/ha in very good years, 4.5 t/ha target, this with fertilizer of 100 kg/ha urea (46% N) plus follow up of 25 kg/ha N. Wheat yields on red-brown earths are similar. Canola yields on both yellow podzols and red-brown earths are 2 t/ha. He can also grow albus lupins. Last year he grew white lupins for a yield of 2.5 t/ha but the average is 2 t/ha. Has not recently grown field peas but an average yield is 2 t/ha.

He does grow lucerne and other perennials. Will grow Lucerne on well-limed yellow podzol soil if deep an alluvial. Will cut hay from lucerne, but also use for silage after grazing (2.5 – 3 t/ha). Lucerne is cut for silage at 10% flowering. He can also graze lucerne again after cutting for silage.

With respect to rotations, on yellow podzols well-established lucerne can last for 8-10 years, then canola-wheat (3 years)-lupins-wheat-pasture. The same rotation is possible on red-brown earths except that lucerne will only last for 3-4 years (less persistent). Overall the cropping percentage is 30%.

Sheep enterprises are Merino ewes with terminal (meat) sires (50%) or Merino rams (50%). Merino wool is superfine (16.5-17 micron). In the wool enterprise the 2 year old ewes at shearing are tested by recording micron counts and individual fleece weights to give a notional fleece value – the highest value ewes are joined to the Merino rams and the lowest to the terminal sires. The average micron count for the district is 18-19.

With respect to stocking rate, some say 15 DSE/ha, but the average has been 9-10 DSE/ha over the last 10 years (drought). For wool prices he budgets to maintain 16.5-17 micron and 1500 c/kg greasy. Wool cut is 4.2-4.4 kg/head for Merino 2 year old ewes. First cross lambs are weaned at 3 months and put onto Lucerne and sold at 6-8 months at 48 kg liveweight. They make $4.5 - $5/kg carcass weight with a dressing percentage of 52%.

In the past he has not sown annual grasses with Lucerne, but has sown them with clover. Other species include sowing 200 ha lucerne last year, he has native perennials (red grass), danthonia (on non-arable country) and phalaris or phalaris/cocksfoot mixes on red-brown earths. In the last 10 years (drought) phalaris has been disappearing, it needs careful management for persistence in Sept-Oct.

Other grazing is opportunistic. In late spring in good years he grazes the non-arable country very hard. Lucerne is grazed until May-June and then locked up. Hay is cut and the sheep are back in December. Ewes at joining (Feb/Mar) go on to Lucerne to increase conception rates. At lambing in July there is a question of whether to put ewes or lambs onto the Lucerne (tradeoff). In Feb/Mar the sheep graze stubble, which is a significant food source.

When asked about mallees, he would be interested – at 12-15 t/ha/year of biomass at $20-30/t, plus a payment of $5/t for nutrient lost. On his best land he would want more than the $130/ha quoted.

When asked whether the sheep enterprise helps with seasonal variability, he said that if the amplitude of events is increasing then perennials can use higher falls of rain in summer, whereas annuals can't. Lucerne gives a greater capacity to utilise unseasonal rainfall. He has more perennials than most people in the district. When asked about the use of farm consultants, it is becoming more common, but he would probably go to other farmers.

We spoke to two researchers at Charles Sturt University at Wagga Wagga. At Tarcutta typically there is sheep and wheat (cereals). A typical rotation could be canola-wheat-wheat-lupins-pasture (4 years). Plant species are tall fescue; phalaris (winter growing, summer dormant) – this is the recommended perennial but not often used; lucerne under sown in wheat or barley at a low rate. But problems have been in establishment in drought years, so now there is more direct sown (seedbed). Animal health issues for lucerne include bloat in cattle and red gut in sheep (lack of fibre in the diet).

Generally the farm cropping percentage is 30%, with a stocking rate of 8 DSE/ha for the whole year (6-7 DSE/ha in mid winter). Rotational grazing is carried more in livestock areas and less in crop areas. Lucerne can be 10-15% of farm area.

For pastures, annuals are ryegrass and clovers, and perennials are phalaris and tall fescue (this has summer and winter active varieties). Phalaris is much more difficult to establish, it is less drought tolerant and doesn't like low pH situations. After a period of time it outcompetes clover, therefore people want to establish phalaris as a true permanent pasture of 20 years. Tall fescue is not commonly used because it doesn't persist as well as phalaris and is difficult to manage in spring. Cocksfoot is a winter-active grass which is also an option in areas of low pH. Rhodes Grass is a tropical grass which produces less biomass. It is a sub-tropical grass that doesn't grow well below Dubbo, but under climate change it could be valuable if there is more summer rainfall.

Under predicted climate change lucerne could be better because it responds to summer rainfall, and new varieties are acid tolerant. Lotus could be suitable in higher rainfall areas (marginal for Tarcutta). The existing climate at Tarcutta is temperate, with uniform rainfall and large variability in summer and winter rainfall.

4.5 South Western Region of VIC (Hamilton)

At Hamilton we spoke with two local researchers. On the question of perenniality if extra lucerne extends the pasture production seasonally, then take advantage of that by, say, changing lambing time and management of animal condition score. The stocking rate can also be adjusted to account for changed seasonal feed distributions. At Hamilton the practice is for early spring lambing. In poor seasons supplementary feeding is necessary, and Lucerne can help in this situation.

If the climate models show a change in feed distribution with an increase in winter feed but a shorter season (decreased feed supply in summer) then an option is to change the time of lambing from September back to August (for wool production) and from July back to June (for meat production). There is evidence of local farmers changing time of lambing and adding Lucerne to their systems in the recent dry years.

We must be careful in modelling systems, because we often assume that other things don't change, whereas farmers do change other management. Other relevant management factors could be the chill index for lambing time. Some shelter analysis has been done but the benefits weren't significant – there was a lamb benefit but no other payments for trees. Twin lambs are more common in this region so lamb survival is important.

A farm consultant was interviewed at Hamilton. He commented that analysis of climate change needs to consider what happens in extreme events, what will be the inherent variability of the climate in the future?

When asked about the role of perennials, he mentioned the high performance pasture work of 10 years ago where ryegrasses in medium term rotations were trialed against perennials. In the last 10 years phalaris has persisted and performed well. Also the fescues (new varieties) have persisted in dry and wet (waterlogged) situations and in low paddock areas. Winter-active Mediterranean fescues have been a bit of a mixed bag; they are free of toxins but have had trouble establishing in southern areas (less sunlight), in hotter areas they have done well. Phalaris has performed very well over the last 10 years. Other ryegrasses have performed well in terms of endophytes, conferring growth advantages (toxins against plant pests), and the newer ryegrasses have had less severe reactions on livestock. AR37 is a new endophyte in a new (patented) ryegrass which has increased plant persistence and reduced adverse effects on livestock. These ryegrasses are easier to establish and more productive. In summary new varieties of phalaris have performed very well in dry and wet (waterlogged) years, ryegrasses are becoming more at their margin and Fescues are promising but we don't know enough about them.

When asked about the feasibility of mallees as energy crops he considered that they were very promising. Trees can increase the productivity of pasture and animal systems by reduction in wind effects and improved shelter. Both pasture growth and lamb survival could be improved, and he referred to work by Rod Bird locally (Bird et al. (2002)) which has been replicated elsewhere in New Zealand and New England. He considered that with 10-30% of the farm in tree shelter lamb survivability would increase by 15% and pasture growth would increase by 10-30%.

When asked about a dollar premium required for mallee to offset long-term profit, he said that there would need to be a premium. CSIRO has worked on spotted gum, which is another tree alternative for graziers.

He also commented on the Carbon Farming Initiative. Under the current Kyoto requirements for permanence (99 year period) farmers would lose flexibility because the trees could not be cut down.

For existing graziers in the district the farming system is totally pasture (no crops). The base EverGraze® system is already being adopted by the top 10% of graziers – perennial ryegrass, sub clover, and lucerne by itself or with perennial grasses (winter active fescues and phalaris). The improved (Triple) system involves Mediterranean (Spanish) phalaris and new ryegrasses. The change in carrying capacity is 30% or more, with less supplementary feeding. Profits can improve by more than 30%, and with an increase in stocking rate profits can improve by 100%.

With respect to grazing management the practice is flexible rotational grazing rather than set stocking. Typical enterprises are Merino sheep with 18 micron wool earning 1500 c/kg clean, or using a terminal sire ram (Dorset Horn or White Suffolk).

The seventh farmer/grazier (and his wife and two sons) commented that they had the driest spell (5 months this year) for a long time and 2005-06 was a very dry year. The soils on his property are very old basalt with some black cracking clays (10%) and some duplex soils. His duplex clay-loam soil is over a buckshot gravel (iron) base. This soil dries out very quickly. Annual average rainfall is 625 mm and very reliable.

His is natural clover country and perennials are very important. Native grasses area silver grass, brome grass and barley grass. He had no annual pastures on the ground at the time of interview. The normal pasture mixes are phalaris and lucerne (20% of farm) and phalaris, annual ryegrass and clover (70% of farm), which are established by spraying and direct drilling. Paddock size is 30-50 ha. Pasture persistence is 10 years for pure lucerne, and the phalaris is permanent. For fertiliser he uses 1 kg P/ha (0.7 – 1 P/DSE) for 4.6 pH soils, and applies K once only.

Pasture hay is cut in October after being locked up for 8 weeks, with a second cut 10 weeks later. Hay is used on his own property. Rotational grazing is practiced – in Summer and Autumn for pastures and Winter and Spring for stock. Improved pastures can be grazed all the time. Phalaris is spelled for 6 weeks in Summer/Autumn. Rotational grazing is done for 2-3 weeks/paddock followed by a 6-week spell.

Lambing is in August/September and weaning in December. Young stock are fed grain (broadcast on ground) – lentil and barley mix. A Merino self-replacing flock produces 18.8 micron wool (2 year old wethers). He has had a cross-bred flock in the past. Fine wool prices are around 1000 c/kg clean (1300 c/kg greasy).

The stocking rate has been up to 20 DSE/ha in the past, but 15 DSE/ha over the last 15 years although currently recovered to 17 DSE/ha. Hand feeding occurs in March/April. The season break is normally around 7 April. Changing stocking rate gives the biggest bang for the buck.

When asked about his attitude to risk, he implements a high stocking rate with supplementary feeding and uses substantial fertilizer to maintain pasture supply. Weeds are less of a problem with fertilizer and good pastures. He applies a capital application of superphosphate (600 kg/ha) and Annual applications of 125 kg/ha (a bag to the acre).

When asked about climate change he considered that if it becomes drier in winter and wetter in summer he will be able to increase his stocking rate. Being drier in winter will reduce waterlogging, and lucerne does better in summer with more rainfall. It is impossible to feed grain in winter – unable to access the paddocks and can't put grain out into water.

With respect to lucerne varieties he observed that lucerne performed very well in the EverGraze® trial. The new lucerne 7 varieties have different growth patterns – summer active and winter dormant, summer and winter active, and winter active and shorter term. He is using the SARDI7 variety from the EverGraze® trial at Hamilton, also Stamina variety which has been selected under very heavy grazing. Lucerne doesn't reseed but some plants can live up to 15 years. Weeds in lucerne need to be sprayed (Sprayseed and Diuron). South of Hamilton is ryegrass country and north of Hamilton is phalaris country.

He has tried tall fescues but is not happy with them (leaf not palatable; substantial growth in spring when other growth is present, but not much growth at other times of the year). Cocksfoot is worthwhile on some areas of his farm, but doesn't handle waterlogging. Demeter Fescue was OK in wetter areas. But phalaris beats them all. Chicory is only an alternative to lucerne and lucerne is easier to manage.

With respect to the adaptive capacity of farmers he was strongly of the opinion that they will adapt to change and technology will develop to help the process. Farmers manage the weather on a daily basis, not a 30-year basis. They are already adaptive managers with flexibility and options.

The eighth farmer/grazier was very interested in new plant species being developed over the next 30 years, and stated that perenniality was the technology.

On his property the sheep enterprises were wool and meat, with 40% crop (canola, wheat and barley). Cropping was after lucerne. After the autumn break in April the soil is sprayed and sown. Wheat and canola are sown into established lucerne. Lucerne lasts a long time – 13 years is his oldest paddock with 6-7 years of overcropping. Non-arable land has native pastures and weeds.

Crop yields are 2 t/ha average for canola (range 1.2 – 2.8) and 4 t/ha for wheat (range 1.5 – 6). Pastures carry 15 DSE/ha over the whole farm. Forty percent of the area is cropped (with no stock for 6 months). Wheat stubble and young crops are grazed. Paddock sizes range from 5 – 38 ha (average 24 ha).

Simple rotational grazing is practiced – larger mobs (1000 – 1200 head) grazed for 10 -14 days, or 750 lambs for 2 weeks. Pastures respond to summer rain. He aims to get Lucerne onto the farm except for the catchment areas. He relies on surface water runoff into dams, therefore sets aside a catchment area for harvesting water.

He has previously established sub-surface pipes (drains under the surface) which allowed him to grow crops in wet areas. Now that he grows lucerne the pipes don't run.

His crop rotation was originally wheat-canola-wheat-canola. Originally he had problems getting canola to establish in wheat straw. Now with lucerne being incorporated into the cropping system, lucerne is grown with crops so that the rotation is wheat/lucerne-grazing lucerne-canola/lucerne-wheat/lucerne. This pasture cropping is now on 40% each year. This is a way to control weeds – once the weeds become too great in the crop he reverts to Lucerne only.

His average rainfall is 650 mm. Soils are podzols (red gum country) and sandy clay loams. These are very old soils, not volcanic and not very fertile. Other soils on the property are deep sands (1%), heavy clays (10%), and the podzols (89%).

He is looking for new plant varieties to suit drier winters and wetter summers. If these become available pasture production will increase. The price of wheat will determine whether he targets crop yields or lucerne and sheep. This provides management flexibility in conjunction with varying moisture supply.

He cuts silage from Lucerne (not hay) but uses only on his farm (rarely sells). Potash is too expensive to sell the nutrients in the hay. Normally he cuts 900 – 1000 wet tonnes of silage off 3-4 paddocks (10-12 t/ha of wet silage). He makes silage from weedy crops or paddocks being set up for Millet or rape – needs to use up the water. The paddock will be locked up in September for 6 weeks, cut in October and then a summer crop is direct drilled (millet or rape for feed). If he doesn't grow a summer crop then Lucerne is maintained for grazing.

His pastures generally are clover, phalaris, and perennial ryegrass with some lucerne. He produces wool and meat from Merino ewes – the meat lambs from mating with Doonie and White Suffolk rams. He has some Merino wethers as the cropping has dropped off. He lambs in July/August although this is the worst time for pasture. In spring he uses set stocking while the lambs are there (up to the end of October). He remains flexible in grazing management depending on the seasonal and price circumstances. Some lambs are sold in December but most in January/February after feeding. He makes silage in mid January if the spring fails. He also feeds grain to young sheep (not the adults). Lambs area kept on Lucerne for finishing and supplemented with grain.

His lamb target weight is 18-20 kg dressed weight (dressing percentage of 47%, or 38-42 kg liveweight. For prices he achieves an average micron of 19.6 and receives 1000 c/kg greasy (1430 c/kg clean).

With respect to biomass tree crops, it all depends on the return per hectare. He considers that trees should not be grown anywhere in areas where rainfall is greater than 400 mm. The blue gum saga has been a shambles for pastoralists. He considers that he is 'feeding and clothing the world'. Biomass tree crops are certainly feasible and his attitude is 'show me the money'. With respect to trees and carbon he is strongly against locking up land for 100 years. With respect to climate change he sees mainly positives in his area if there is less rain in winter and more in summer. He sees the biggest risk being carbon policy if it requires sequestering and permanence.

If there is more summer rain then he would consider double (summer) cropping; he is interested in polymer-coated summer crop seed. Other technologies that would be beneficial include more salinity tolerant species, perennial wheat with lucerne-like roots, Taurus and Lotus.

5. Historical and projected climate data

Summary

When climate series for daily minimum and maximum temperature and monthly rainfall were compared for the historical record (over the years 1971 to 2011) against predictions (for the years 2012 to 2052) using 18 GCMs there was a consistent story from the information presented in this chapter. Using the GCMs discussed here, and after downscaling to the four project locations and conducting bias correction, the climate series were examined graphically and using statistical procedures.

Daily minimum and maximum temperatures are generally predicted to be higher in the future, but the situation is less clear for rainfall. Although visually the future distributions seem to be lower, statistical tests for the rainfall series indicated less evidence for change.

Another feature of this analysis is that there is stronger statistical evidence for changes in the means of distributions than in the variances of the distributions. The non-parametric tests were not able to provide information indicating that the variability may change very much. It might be expected that the central tendency and variability of selected climate series would both change. There is little evidence of the latter in the results presented here. Whether this will become a reality is a question that we are not in a position to answer at present, due either to our inability to extract a clear signal from noisy data or because this is an artifact of the climate downscaling process, or both.

5.1 Purpose

The central issue of this project relates to the performance of agricultural plants and agricultural systems under predicted climate change, compared to what has happened in the past. This information is used to investigate economic incentives to adapt and change under a predicted climate. The approach used does not account for other factors (e.g. human and social capital) that form part of adaptive capacity and that are required to turn options into action.

To test this question we first obtained historical and predicted climate series for the four project locations and examined these data. The climate series available were historical (1889 to 2011) from SILO agro-meteorological patched point data sets (Jeffrey et al. (2001)) and predicted series (1900 to 2098) from Global Climate Models (GCMs). Eighteen GCMs for the A2 emission scenario (Nakicenovic and Stewart (2000), Anwar et al. (2012)) were available and were statistically downscaled (Liu and Zuo 2012) to the project locations. The future climate scenario of 2030 Dry was used for this study.

Of primary interest for our purposes was whether the predicted (future) climate series differ very much from the historical climate record and, if so, whether such differences were reflected in plant growth parameters. These potential plant differences, manifest in key plant growth parameters, will be tested with biophysical simulation models. The potential parameter differences are of interest for the economic analysis. If there are substantial differences in plant growth for the predicted compared to historical climate record, which lead to changed plant growth performance, then such information is the basis for the economic analysis of future farming system outcomes under predicted climate change.

But we also need to consider the question of ‘which GCM’ since, with 18 potential sources of climate data, we were interested in whether there is much difference between GCMs. In a practical sense this question has implications for the analytical task within the project. Limits to the project resources and time scales meant that it was impossible to analyse 18 possible climate futures. And we needed to reduce the dimensionality of the analysis to a meaningful level. The CSIRO Mark3.5 (S2) GCM developed in Australia, which generally predicts hotter and drier conditions consistent with other GCMs, was used for analysis of a predicted future climate.

The purpose of this chapter is to describe the process of developing climate data for the four project sites, and then compare the forecast climate predictions with the historical record to see if there is much difference.

It is important to note that when comparing climate series we must compare the whole distribution so that measures of central tendency, variation and extreme values associated with distributions are considered. In this chapter we present visual (graphical) comparisons and statistical analysis to present data, make comparisons and draw conclusions.

5.2 Climate data

The climate series available were historical (1889 to 2011) from SILO agro-meteorological patched point data sets (Jeffrey et al. (2001)) and predicted series (1900 to 2098) from GCMs. Eighteen GCMs for the A2 emission scenario (Nakicenovic and Stewart (2000), Anwar et al. (2012)) were available and were statistically downscaled (Liu and Zuo 2012) to the project locations. Information about these GCMs from a Multi-Model Dataset is in World Climate Research Program (2013). The list of GCMs is in Table 5.1.

The time periods used for this project were 40 years of SILO (1971-2011) and 40 years of future (2012-2052) climate (based on the 2030 Dry Climate Scenario). The original climate data provided were from 1898 to 2098, and the above yearly subsets were used in the analysis.

The procedure for statistically downscaling of daily climate variables was the same as reported by Liu and Zou (2012). The monthly climate projections for GCMs were first downscaled to the four project study sites using an inverse distance-weighted interpolation method. A bias correction procedure was then applied to the monthly GCM values for each site. Daily climate projections for each site were generated using a stochastic weather generator.

5.3 Bias correction

The procedure of bias correction was that observed (historical) and GCM projected monthly climate data were analysed for each calendar month for the period 1971-2011. For each climate variable and calendar month the 40 historical and 40 raw GCM values obtained in spatial downscaling were sorted separately in an ascending order. The observed and GCM data were then paired according to their rank, or quartile, and plotted to yield a q-q plot. Linear least squares regressions were then conducted on the whole set of paired data (Liu and Zuo 2012).

Table 5.1 List of 18 Global coupled ocean-atmosphere GCMs* under A2 emission scenario used in this study for statistical downscaling outputs

Name of GCM	Abbreviation of GCM	Country	Centre
BCCR-BCM2.0	BC	Norway	Bjerknes Centre for Climate Research
CGCM3.1(T47)	CM	Canada	Canadian Centre for Climate Modelling and Analysis
CNRM-CM3	CN	France	Centre National de Recherches Meteorologiques
CSIRO-Mk3.0	S1	Australia	Commonwealth Scientific and Industrial Research Organisation (CSIRO)
CSIRO-Mk3.5	S2	Australia	CSIRO
ECHAM5/MPI-OM	EC	Germany	Max-Planck Institute for Meteorology
ECHO-G	EG	Germany/Korea	Meteorological Institute /University of Bonn & Model and Data Group at MPI-M
GFDL-CM2.0	G1	USA	Geophysical Fluid Dynamics Laboratory
GFDL-CM2.1	G2	USA	Geophysical Fluid Dynamics Laboratory
GISS-ER	GH	USA	Goddard Institute for Space Studies
UKMO-HadCM3	HA	UK	UK Meteorological Office
UKMO-HadGEM1	HG	UK	UK Meteorological Office
INM-CM3.0	IN	Russia	Institute for Numerical Mathematics
IPSL-CM4	IP	France	Institute Pierre Simon Laplace
MIROC3.2(medres)	MM	Japan	Meteorological Research Institute Japan
MRI-CGCM2.3.2	MR	Japan	National Institute for Environmental Studies
CCSM3	NC	USA	National Centre for Atmospheric Research
PCM	NP	USA	National Centre for Atmospheric Research

* See website at http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php.

The q-q plot relationship is a comparison of two cumulative distribution functions (CDFs). If the two distributions are linearly related, the points in the q-q plot lie on a line. If all points in the q-q plot lie on a 1:1 line, the two distributions are identical. Under the assumption that the GCM bias change for a climate variable follows the function of the distribution and is linearly related to the magnitude of the observed values of that variable in q-q plot, a linear interpolation approach is used to transfer future GCM values that are within the range of the GCM projections for the period 1971-2012 through the method that matches the two CDFs in q-q plot. The bias-corrected monthly GCM projected monthly vales are the difference between the means of the historical and the climate change period for 1971-2011. When considering the climate change projections for the period 1971-2011, this is referred to as the hindcast period (Liu and Zuo 2012).

It is expected that the q-q plots before bias correction would diverge largely from 1:1 lines as the GCM projected monthly raw values greatly disagree with observed monthly values. Examples can be seen from the Figure 6 of Liu and Zuo (2012) which shows the detailed discussion on this issue.
In this report, we do not show the after bias corrected q-q plots as many other aspects of bias correction and statistical tests of the downscaling approach are not within the scopes of this report, but they are available in the Liu and Zuo (2012).

To develop the future GCM projected values outside the GCM hindcast period, the bias correction was extrapolated from the whole-period linear relationship.

5.4 Climate series and comparisons for the project

The climate series of interest to this analysis were the SILO data for the period 1971-2011 and the predicted climate data for the period 2012-2052. Climate change (hindcast) data for the period 1971-2011 were also developed for bias correction, but were not used in the analysis.

The climate variables of interest to this project were daily minimum temperature, maximum temperature, and rainfall for subsequent plant modelling.

In the plant biophysical modelling (e.g. Keating et al. (2003) for APSIM) the maximum and minimum temperature, rainfall and radiation series are used to determine evaporation data required for the crop modelling. Results presented here are for maximum and minimum temperatures and rainfall.

The questions associated with a comparison of these climate series were:

1. What do the annual distributions for the climate variables of interest look like?; and
2. How do the annual and monthly distributions of the 18 GCMs compare with the historical sequence?

Initially we compared at the annual distributions, after which we studied the monthly patterns for one GCM (future) with the historical climate series. In this chapter these comparisons are made by presentation of graphs and by statistical testing.

5.4.1 Choice of GCM for further analysis

Due to limitations in project resources and the time frame it was not possible to conduct analyses for 18 possible climate futures. As well, there was an intrinsic need to reduce the dimensionality of the problem to make the analysis meaningful. After examining the climate data a decision was made to choose the CSIRO-Mk3.5 (S2) GCM to represent the future climate in this project. Predictions from all the 18 GCMs were reasonably consistent compared to the historical record (see for example Figure 5.1). S2 is an Australian model developed for the Australian environment and climate. Some important impact analyses conducted with the S2 model have been conducted by Anwar et al. (2007), CSIRO (2009), Wang et al. (2010) and Dunlop et al. (2012).

5.5 Statistical testing of climate series

In this project the questions are whether the forecast climate series are very different from the historical record and whether any such differences are significant for climate risk management. In this chapter we assess the first of these questions by graphical comparisons of data and statistical tests of differences between distributions. However, even if there are differences in forecast climates for key climate variables it is not necessarily the case that these differences matter. Subsequently the climate forecasts are translated into predicted plant responses and farming systems analysis to answer the second question.

The statistical question is whether the forecast climate series are different to the historical series. The null hypothesis is that the series being compared (each future versus the historical record) have the same characteristics (i.e. whether the whole distributions are not statistically different). The tests applied were the Kruskall-Wallis (K-W) rank sum test and the Siegel-Tukey (S-T) rank sum dispersion test (Liu and Zou (2012), Kanji (1993)). These tests are, respectively, for whether the two distributions have the same mean and equal variance. They are non-parametric tests for whether samples are likely to originate from the same distribution, i.e. whether the sample distributions are independent or unrelated. If the test statistic is in the critical regions then the null hypothesis is rejected and the conclusion is that the climate distributions are different.

If a null hypothesis is rejected (e.g. for mean minimum temperature) and the future mean value is higher, then we can say that the future level is likely to be higher despite the test being two-sided. If the null hypothesis is rejected (e.g. for variance of rainfall) but the graph is unclear about likely changes, then we can only say that the variances are significantly different without indicating a direction of change.

The tests reported are for the historic series versus individual forecast series as represented by the 18 GCMs. The data for historical and 18 GCM series for mean minimum and maximum daily temperatures by month and annual rainfall are in Appendix B. By convention a 0.05 significance level was adopted as the statistical threshold for hypothesis testing.

5.6 Results

5.6.1 Cunderdin

5.6.1.1 Graphical climate distributions for Cunderdin

The graphical results presented are annual distributions for the variables of interest and monthly mean distributions of these variables for historical and future climates.

Figures 5.1 and 5.2 contain the distributions of daily minimum and maximum temperatures for historical (SILO) (1971-2011) and 18 forecast GCMs (2012-2052), and Figure 5.3 contains the distributions of annual rainfall for SILO and 18 forecast GCMs for these periods. In each case the distributions are ordered by increasing distribution mean and named by the abbreviations in Table 5.1. In each box and whisker plot the dot is the mean, the box shows the 25th (lower end), 50th (horizontal bar) and 75th (upper end) percentiles, and the lower and upper lines indicate the extremes of minimum and maximum values of the distributions.

Examination of Figures 5.1 to 5.3 shows that there is substantial overlap between the 18 GCM climate distributions for daily maximum and minimum temperature and rainfall. And for each variable the historical series is either within the range of the GCMs or at the lower end for the daily maximum. Generally the SILO series for both temperatures are towards the low end of the future series, and the SILO rainfall distribution is towards the high end of the future series. Thus in the 2030 dry scenario the temperature is generally expected to be higher, and the rainfall lower, than in the past.

For agricultural systems the seasonal distribution of these variables are very important. Figures 5.4 and 5.5 contain the monthly distributions of SILO and S2 for daily minimum and maximum temperature, and Figure 5.6 contains the monthly distribution of rainfall for these series.

Both the maximum and minimum temperature distributions for each month are higher for the S2 than the SILO series. But the rainfall is generally lower in the summer and higher in the late winter and early spring months.

5.6.1.2 Statistical analysis of the Cunderdin distributions

Tables B.1, B.2 and B.3 in Appendix B contain mean SILO and 18 GCM values for minimum and maximum daily temperature, and monthly rainfall. These numbers show how the average values vary over the 18 GCMs and 12 months. There is substantial variation in these series but the general trends of Figures 5.1 to 5.6 are confirmed.

The K-W and S-T test (section 5.5) results are presented in Table 5.2 for the case of SILO versus S2 at Cunderdin. For the K-W statistic (testing that the populations have the same mean) there are a substantial number of months (10 of 12 for maximum and 12 of 12 for minimum temperature) where the hypothesis is rejected, so that the mean climate change temperatures are predicted to be higher. However, for rainfall there are only 2 months where the mean is predicted to be lower.

For the S-T test of population variances there are no months for temperature and only two months for rainfall where statistically the variance of temperatures or rainfall differs between SILO and the GCM forecasts.

Table 5.3 contains a summary of the K-W and S-T tests for monthly climate change for all 18 GCMs compared to the historical record at Cunderdin. The K-W results show that of the 216 possibilities (18 GCMs x 12 months) the mean maximum temperature is indicated to increase in 159 cases, the mean minimum temperature is indicated to increase in 176 cases, and rainfall is indicated to be lower in 27 cases. The S-T results are that the variance of maximum and minimum temperature will change in 8 and 14 cases, and that it will change in 52 cases for rainfall.

Table 5.2 Statistical tests (K-W and S-T) for differences between historical (1971-2011) and CSIRO Mk3.5 (2012-2052): Cunderdin

	Test	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	K-W	0.00*	0.00*	0.24	0.04*	0.00*	0.00*	0.00*	0.00*	0.00*	0.11	0.01*	0.00*
	S-T	0.5	0.21	0.39	0.12	0.27	0.74	0.55	0.86	0.61	0.67	0.85	0.71
Tmin	K-W	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.01*	0.00*	0.00*
	S-T	0.94	0.67	0.1	0.96	0.53	0.61	0.2	0.34	0.76	0.48	0.29	0.85
Rain	K-W	0.33	0.97	0.03*	0.81	0.52	0.28	0.17	0.19	0.37	0.92	0.04*	0.83
	S-T	0.00*	0.01*	0.36	0.15	0.46	0.14	0.61	0.37	0.73	0.2	0.74	0.00*

* $p<0.05$ so that the null hypothesis is rejected

5.6.1.3 Summary for Cunderdin

Predictions of future climates are made using models, which are based on sets of relationships, parameters and other data. The GCMs used here have been developed based on different views of climate drivers. Hence differences in model predictions are to be expected. But the process of scientific advance and peer review should develop models which are reasonably consistent in their predictions.

Table 5.3 Summary of statistical tests for differences between historical (1971-2011) and 18 GCM projected (2012-2052) monthly climate: Cunderdin

	Number of null hypothesis rejected (out of 216)*	
	Kruskall-Wallis (mean)	Siegel-Tukey (variance)
Maximum daily temperature	159	8
Minimum daily temperature	178	14
Annual Rainfall	27	52

* 12 months and 18 GCMs

The data presented here allow comparison of the recent historical climate record with a relatively short forecast future. For Cunderdin in WA the consensus of the predictions is that the future climate will be warmer and drier.

The comparison of one future prediction against the historical record shows that minimum and maximum temperatures are likely to increase in most months. The pattern of rainfall change is less consistent, with rainfall lower in summer and higher in other seasons. However, tests concerning potential changes in the variability in future climates showed that substantial changes in the overall variance seem to be unlikely.

5.6.2 Katanning

5.6.2.1 Graphical climate distributions for Katanning

Examination of Figures 5.7, 5.8 and 5.9 shows that there is substantial overlap between the 18 GCM climate distributions for daily maximum and minimum temperature and rainfall. And for each variable the historical series is within the range of the GCMs. However, generally the historical series for both temperatures are towards the low end of the future series, and the historical rainfall distribution is towards the high end of the future series.

The rankings of predicted temperatures according to historic (SILO) GCM are similar to the rankings for Cunderdin. Generally in the 2030 Dry scenario temperatures are expected to be higher, and the rainfall lower, than in the past.

The seasonal distributions of these variables for SILO and S2 are in Figures 5.10, 5.11 and 5.12. Minimum and maximum daily temperatures are expected to rise over the whole year. Future monthly rainfall looks to be lower in spring and summer but some increase may be observed in June, August, September, March and April.

5.6.2.2 Statistical analysis of the Katanning distributions

Tables B.4, B.5 and B.6 contain mean historical and 18 GCM values for minimum and maximum daily temperature, and monthly rainfall. These numbers show how the average values vary over the 18 GCMs and 12 months. There is substantial variation in these series but the general trends of Figures 5.7 to 5.12 are confirmed.

The K-W and S-T test results are presented in Table 5.4 for the case of historic versus S2 at Katanning. For the K-W statistic (testing that the populations have the same mean) there are a substantial number of months (10 of 12 for maximum and 12 of 12 for minimum temperature) where the hypothesis is rejected. Given the change in predicted means, this result is that that mean climate change temperatures are predicted to be higher. However, for rainfall there are only 2 months where the mean is predicted to be different. These months (March and November) can be observed in Figure 4.10, but it is not clear from that figure whether the monthly rainfall is expected to rise or fall, and there are other months where the graphs seem to indicate that changes in the means may occur. Overall the K-W tests for changes in mean monthly rainfall do not indicate substantial or consistent changes in the monthly rainfall distributions.

From the S-T tests of population variances at Katanning in Table 5.4 there are no months for temperature and only 3 months for rainfall where statistically the variance of distributions differs between historical and the S2 forecasts. These predicted climate series do not appear to show substantial changes in the variability of climate for historical versus the S2.

Table 5.5 contains a summary of the K-W and S-T tests for monthly climate change for all 18 GCMs compared to the historical record at Katanning. These results show that of the 216 possibilities (18 GCMs x 12 months) the mean maximum temperature is indicated to change in 171 cases, the mean minimum temperature in 178 cases, and average rainfall in 33 cases. The S-T results are that the variance of maximum and minimum temperature will change in 9 and 4 cases, and that it will change in 33 cases for rainfall.

Table 5.4 Statistical tests (K-W and S-T) for differences between historical (1971-2011) and CSIRO Mk3.5 (2012-2052): Katanning

	Test	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	K-W	0.00*	0.00*	0.24	0.04*	0.00*	0.00*	0.00*	0.00*	0.00*	0.11	0.01*	0.00*
	S-T	0.5	0.21	0.39	0.12	0.27	0.74	0.55	0.86	0.61	0.67	0.85	0.71
Tmin	K-W	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.01*	0.00*	0.00*
	S-T	0.94	0.67	0.1	0.96	0.53	0.61	0.2	0.34	0.76	0.48	0.29	0.85
Rain	K-W	0.33	0.97	0.03*	0.81	0.52	0.28	0.17	0.19	0.37	0.92	0.04*	0.83
	S-T	0.00*	0.01*	0.36	0.15	0.46	0.14	0.61	0.37	0.73	0.2	0.74	0.00*

Table 5.5 Summary of statistical tests for differences between historical (1971-2011) and 18 GCM projected (2012-2052) monthly climate: Katanning

	Number of null hypothesis rejected (out of 216)*	
	Kruskall-Wallis (mean)	Siegel-Tukey (variance)
Maximum daily temperature	171	9
Minimum daily temperature	178	4
Annual Rainfall	33	33

* 12 months and 18 GCMs

5.6.2.3 Summary

At Katanning similar trends to Cunderdin for predicted climate series against the historical record are observed. There are stronger statistical grounds for a change (rise) in daily minimum and maximum temperatures than for rainfall. Comparison of seasonal trends for these climate series indicate a consistent increase in daily temperatures, but monthly rainfall distributions seem to change less in a statistical sense.

5.6.3 Wagga Wagga

5.6.3.1 Graphical climate distributions for Wagga Wagga

Examination of Figures 5.13, 5.14 and 5.15 shows that there is substantial overlap between the 18 GCM climate distributions for daily maximum and minimum temperature and rainfall. For each variable the historical series is within the range of the GCMs. However, generally the historical series for both temperatures are towards the low end of the future series, and the historical rainfall distribution is towards the high end of the future series.

The rankings of predicted temperatures according to the historic and GCM series are similar to the rankings for Cunderdin and Katanning. Generally in the 2030 Dry scenario temperatures are expected to be higher, and the rainfall lower, than in the past.

The seasonal distributions of these variables for SILO and S2 are in Figures 5.16, 5.17 and 5.18. Minimum and maximum daily temperatures are expected to rise over the whole year. Future monthly rainfall looks to be lower in all months at Wagga Wagga.

5.6.3.2 Statistical analysis of the Wagga Wagga distributions

Tables B.7, B.8 and B.9 contain mean historical and 18 GCM values for minimum and maximum daily temperature, and monthly rainfall. These numbers show how the average values vary over the 18 GCMs and 12 months. There is substantial variation in these series but the general trends of Figures 5.13 to 5.17 are confirmed.

The K-W and S-T test results are presented in Table 5.16 for the case of historic versus S2 at Tarcutta. For the K-W statistic there are a substantial number of months (11 of 12 for maximum and 11 of 12 for minimum temperature) where the hypothesis is rejected. Given the change in predicted means, this result is that that mean climate change temperatures are predicted to be higher. However, for rainfall there are only 3 months where the mean is predicted to be different. These months (March, June and August) can be observed in Figure 4.15, but it not clear from that figure whether the monthly rainfall is expected to rise or fall, and there are other months where the graphs seem to indicate that changes in the means may occur. Overall the K-W tests for changes in mean monthly rainfall do not indicate substantial or consistent changes in the monthly rainfall distributions.

From the S-T tests of population variances at Tarcutta in Table 5.16 there are no months for temperature and only 2 months for rainfall where statistically the variance of distributions differs between historical and the S2 forecasts. These predicted climate series do not appear to show substantial changes in the variability of climate for historical versus the S2.

Table 5.17 contains a summary of the K-W and S-T tests for monthly climate change for all 18 GCMs compared to the historical record at Tarcutta. The K-W results show that of the 216 possibilities the mean maximum temperature is indicated to change in 151 cases, the mean minimum temperature is indicated to change in 167 cases, and average rainfall is indicated to change in 23 cases. The S-T results are that the variance of maximum and minimum temperature will change in 16 and 18 cases, and that it will change in 15 cases for rainfall.

Table 5.6 Statistical tests (K-W and S-T) for differences between historical (1971-2011) and CSIRO Mk3.5 (2012-2052): Wagga Wagga

	Test	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	K-W	0.00*	0.06	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.01*	0.00*	0.02*
	S-T	0.5	0.55	0.93	0.17	0.85	0.85	0.08	0.08	0.64	0.57	0.41	0.92
Tmin	K-W	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.12	0.00*	0.00*	0.00*	0.00*
	S-T	0.94	0.56	0.58	0.95	0.58	0.33	0.1	0.49	0.92	0.57	0.92	0.37
Rain	K-W	0.33	0.7	0.02*	0.08	0.35	0.01*	1	0.03*	0.8	0.8	0.54	0.86
	S-T	0.00*	0.57	0.6	0.87	0.24	0.2	0.78	0.06	0.31	0.4	0.02*	1

Table 5.7 Summary of statistical tests for differences between historical (1971-2011) and 18 GCM projected (2012-2052) monthly climate: Wagga Wagga

	Number of null hypothesis rejected (out of 216)*	
	Kruskall-Wallis (mean)	Siegel-Tukey (variance)
Maximum daily temperature	151	16
Minimum daily temperature	167	18
Annual Rainfall	23	15

* 12 months and 18 GCMs

5.6.3.3 Summary

At Wagga Wagga similar trends are observed to Cunderdin and Katanning for predicted climate series against the historical record. There are stronger statistical grounds for a change (rise) in daily minimum and maximum temperatures than for rainfall. Comparison of seasonal trends for these climate series indicate a consistent increase in daily temperatures, but monthly rainfall distributions seem to change less in a statistical sense.

5.6.4 Hamilton

5.6.4.1 Graphical climate distributions for Hamilton

Examination of Figures 5.19, 5.20 and 5.21 shows that there is similar substantial overlap between the 18 GCM climate distributions for daily maximum and minimum temperature and rainfall. For each variable the historical series is within the range of the GCMs. However, generally the historical series for both temperatures are towards the low end of the future series, and the historical rainfall distribution is towards the high end of the future series.

The rankings of predicted temperatures according to the historic and GCM series are similar to the rankings for Cunderdin, Katanning and Tarcutta. Generally in the 2030 Dry scenario temperatures are expected to be higher, and the rainfall lower, than in the past.

The seasonal distributions of these variables for SILO and S2 are in Figures 5.22, 5.23 and 5.24. Minimum and maximum daily temperatures are expected to rise over the whole year. Future monthly rainfall looks to be lower in autumn and winter at Hamilton.

5.6.4.2 Statistical analysis of the Hamilton distributions

Tables B.10, B.11 and B.12 contain mean historical and 18 GCM values for minimum and maximum daily temperature, and monthly rainfall. These numbers show how the average values vary over the 18 GCMs and 12 months. There is substantial variation in these series but the general trends of Figures 5.19 to 5.24 are confirmed.

The K-W and S-T test results are presented in Table 5.8 for the case of historic versus S2 at Hamilton. For the K-W statistic (testing that the populations have the same mean) there are a substantial number of months (11 of 12 for maximum and 11 of 12 for minimum temperature) where the hypothesis is rejected. Given the change in predicted means, this result is that that mean climate change temperatures are predicted to be higher. However, for rainfall there are only 2 months where the mean is predicted to be different. Overall the K-W tests for changes in mean monthly rainfall do not indicate substantial or consistent changes in the monthly rainfall distributions.

From the S-T tests of population variances at Hamilton in Table 5.8 there are no months for temperature and only 1 month for rainfall where statistically the variance of distributions differs between historical and the S2 forecasts. These predicted climate series do not appear to show substantial changes in the variability of climate for historical versus the S2.

Table 5.9 contains a summary of the K-W and S-T tests for monthly climate change for all 18 GCMs compared to the historical record at Hamilton. The K-W results show that of the 216 possibilities the mean maximum temperature is indicated to change in 170 cases, the mean minimum temperature is indicated to change in 146 cases, and average rainfall is indicated to change in 26 cases. The S-T results are that the variance of maximum and minimum temperature will change in 9 and 17 cases, and that it will change in 10 cases for rainfall.

Table 5.8 Statistical tests (K-W and S-T) for differences between historical (1971-2011) and CSIRO Mk3.5 (2012-2052): Hamilton

	Test	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	K-W	0.67	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*
	S-T	0.74	0.75	0.09	0.59	0.9	0.98	0.46	0.54	0.92	0.46	0.55	0.86
Tmin	K-W	0.17	0.01*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*
	S-T	0.43	0.94	0.89	0.45	0.97	0.73	0.49	0.66	0.88	0.74	0.5	0.17
Rain	K-W	0.83	0.03*	0.27	0.93	0.01*	0.94	0.18	0.15	0.81	0.45	0.85	0.08
	S-T	0.94	0.29	0.4	0.79	0.95	0.98	0.48	0.24	0.01*	0.13	0.45	0.96

5.6.4.3 Summary

At Hamilton similar trends are observed to Cunderdin, Katanning and Tarcutta for predicted climate series against the historical record. There are stronger statistical grounds for a change (rise) in daily minimum and maximum temperatures than for rainfall. Comparison of seasonal trends for these climate series indicate a consistent increase in daily temperatures, but monthly rainfall distributions seem to change less in a statistical sense. There may be some decrease in monthly rainfall in autumn and winter.

Table 5.9 Summary of statistical tests for differences between historical (1971-2011) and 18 GCM projected (2012-2052) monthly climate: Hamilton

	Number of null hypothesis rejected (out of 216)*	
	Kruskall-Wallis (mean)	Siegel-Tukey (variance)
Maximum daily temperature	170	9
Minimum daily temperature	146	17
Annual Rainfall	26	10

* 12 months and 18 GCMs

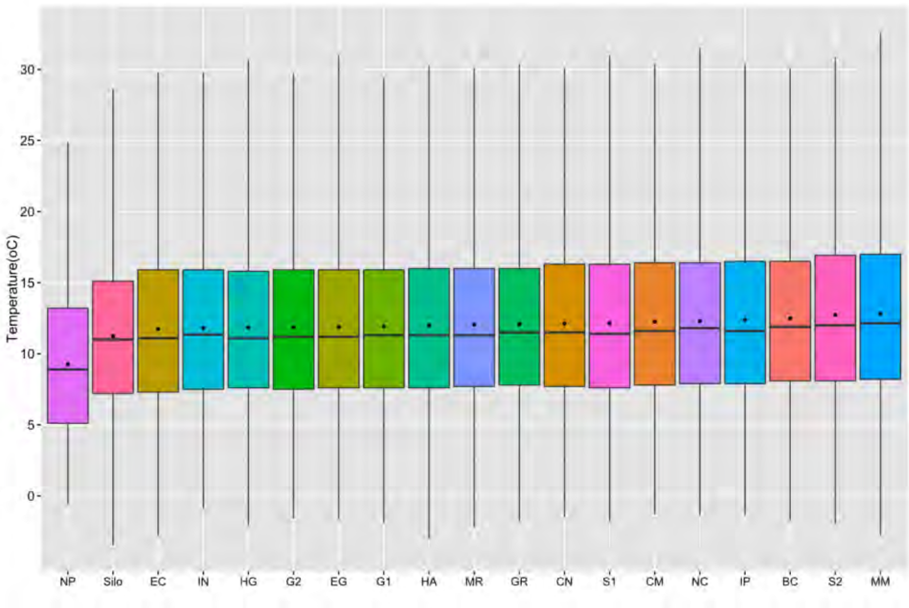


Figure 5.1 Distributions of daily minimum temperature: SILO and 18 forecast GCMs: Cunderdin

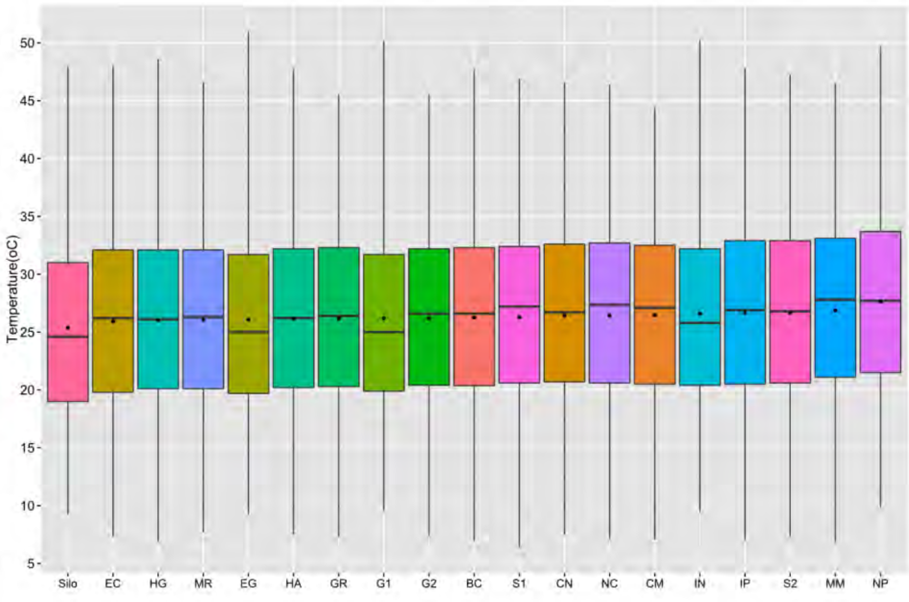


Figure 5.2 Distributions of daily maximum temperature: SILO and 18 forecast GCMs: Cunderdin

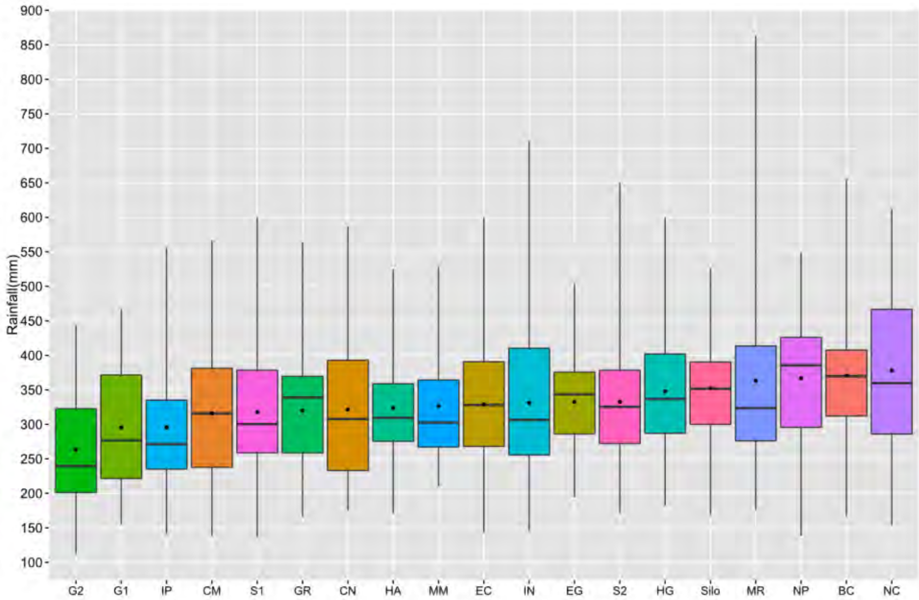


Figure 5.3 Distributions of annual rainfall SILO and 18 forecast GCMs: Cunderdin

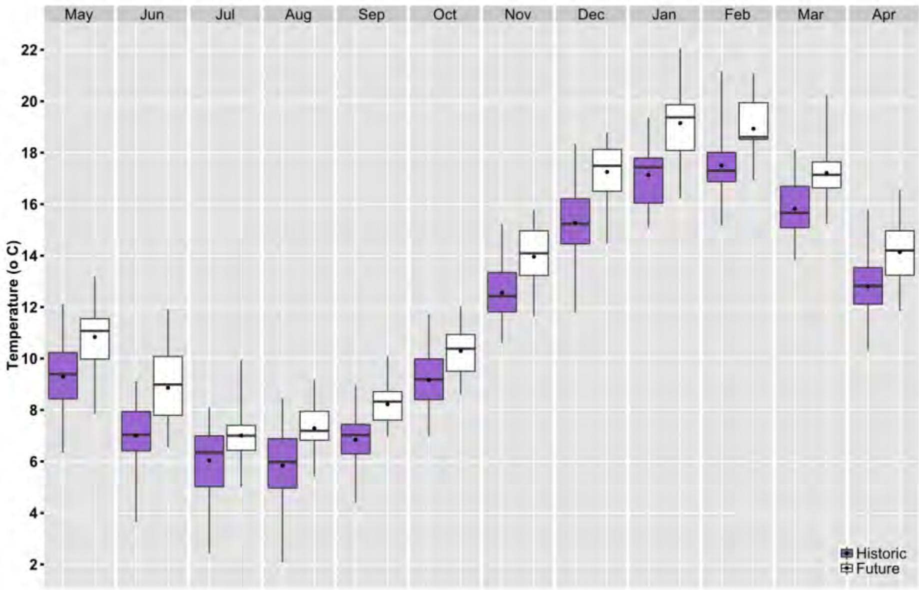


Figure 5.4 Distributions of monthly mean minimum temperature: SILO and S2: Cunderdin

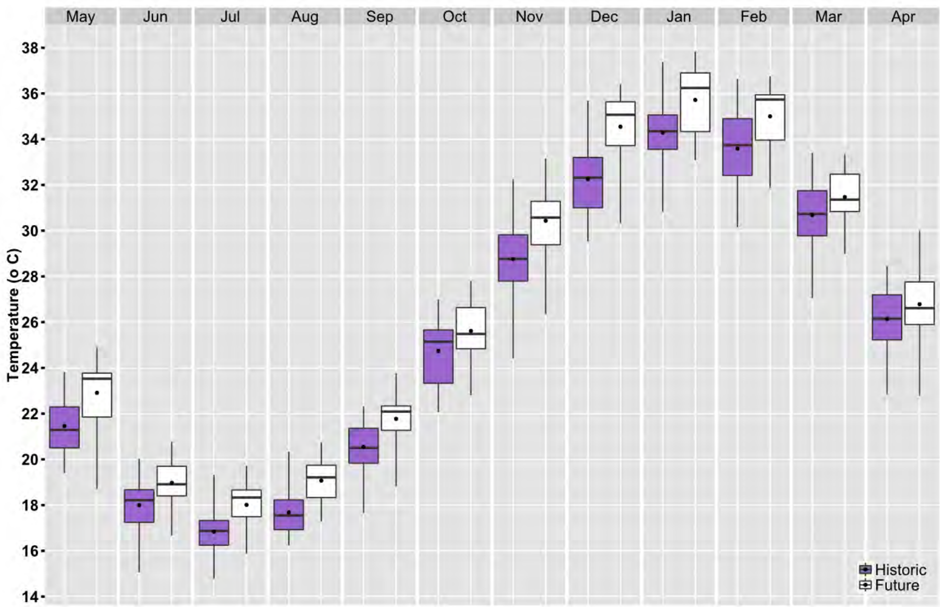


Figure 5.5 Distributions of monthly mean maximum temperature: SILO and S2: Cunderdin

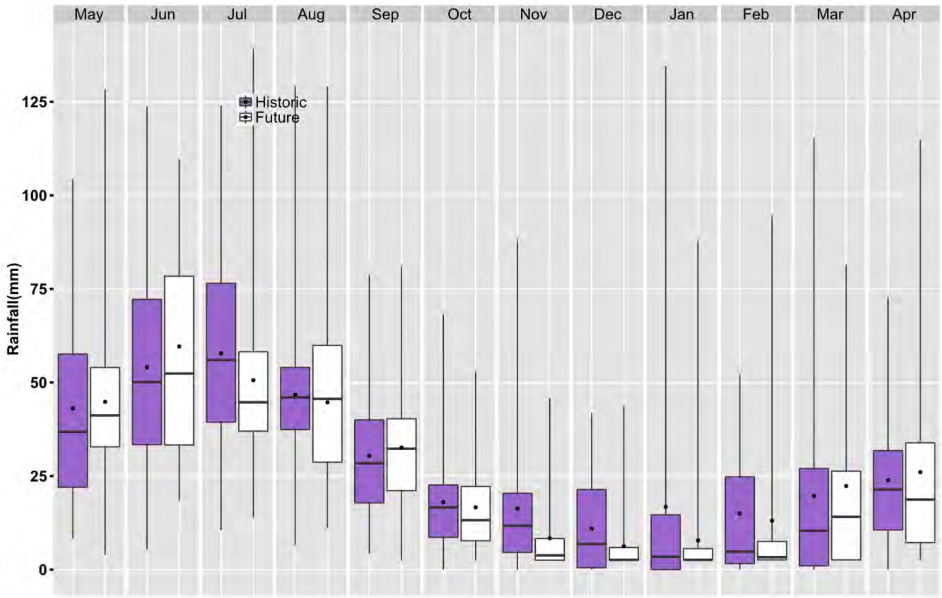


Figure 5.6 Distributions of monthly rainfall: SILO and S2: Cunderdin

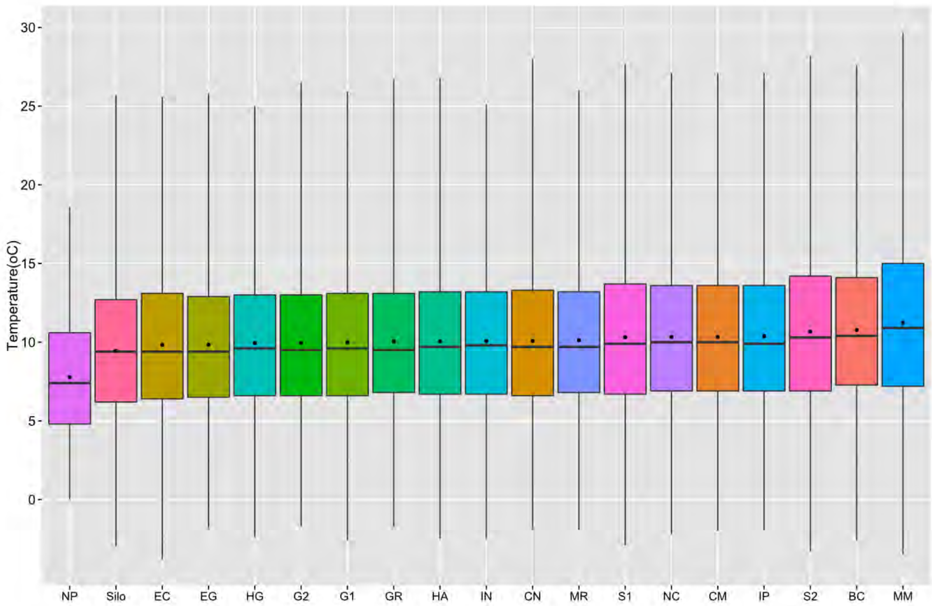


Figure 5.7 Distributions of daily minimum temperature: SILO and 18 forecast GCMs: Katanning

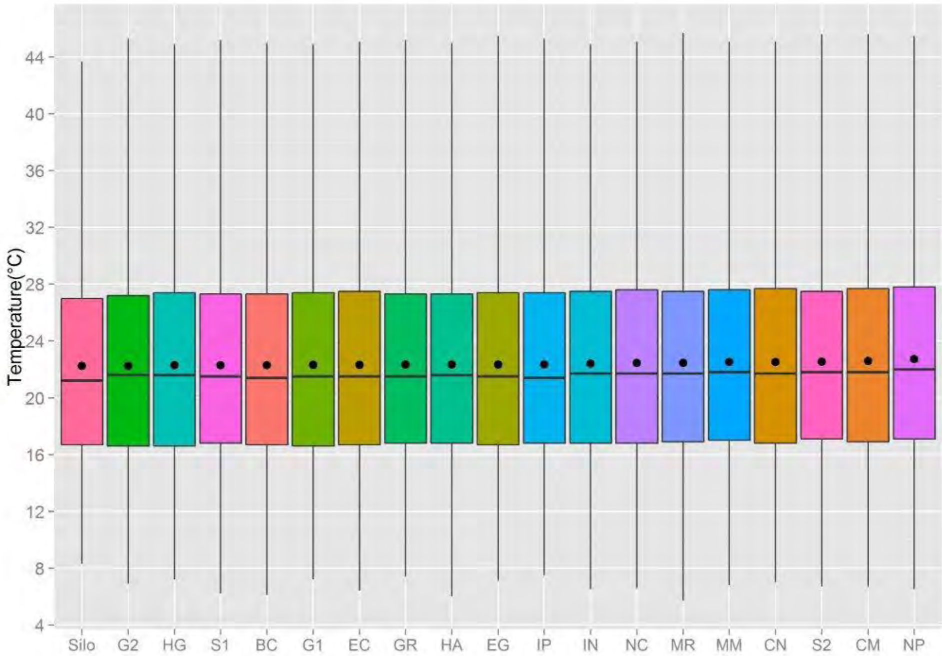


Figure 5.8 Distributions of daily maximum temperature: SILO and 18 forecast GCMs: Katanning

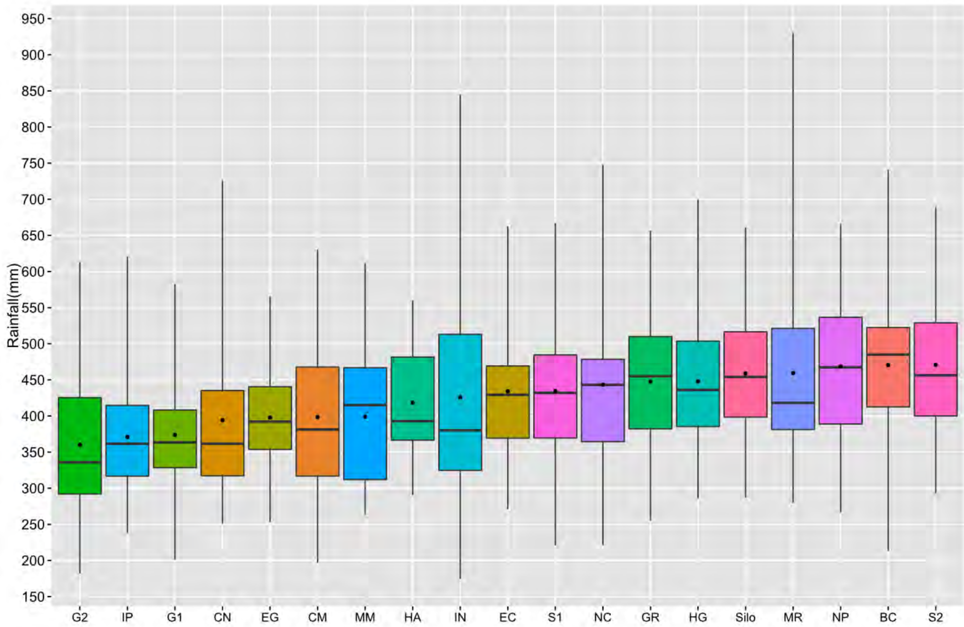


Figure 5.9 Distributions of annual rainfall: SILO and 18 forecast GCMs: Katanning

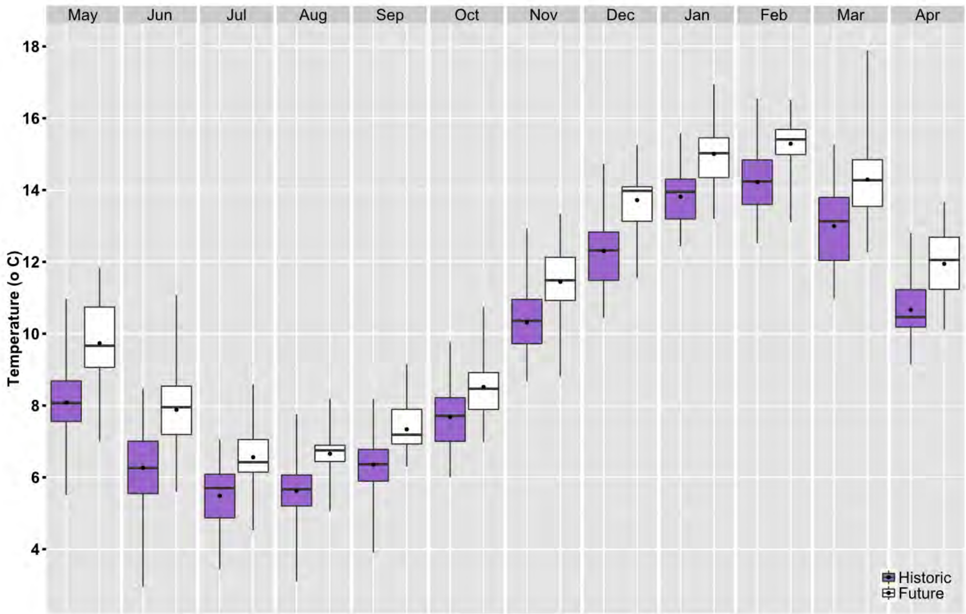


Figure 5.10 Distributions of monthly mean minimum temperature: SILO and S2: Katanning

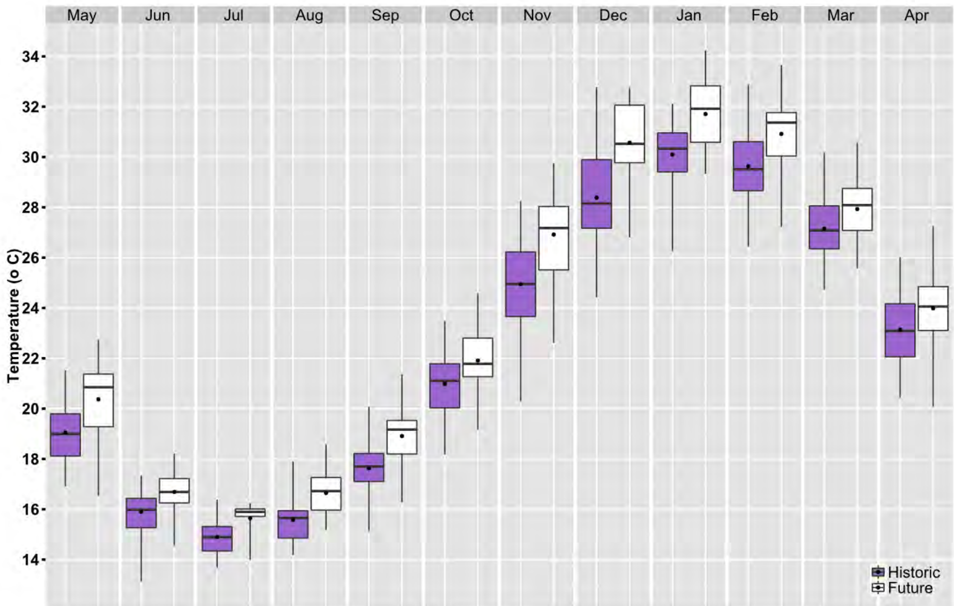


Figure 5.11 Distributions of monthly mean maximum temperature: SILO and S2: Katanning

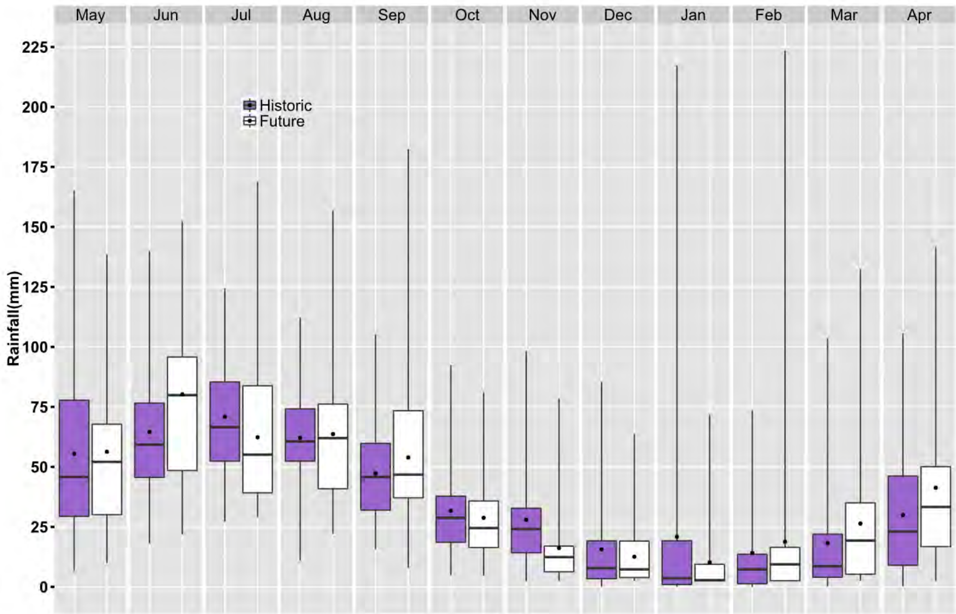


Figure 5.12 Distributions of monthly rainfall: SILO and S2: Katanning

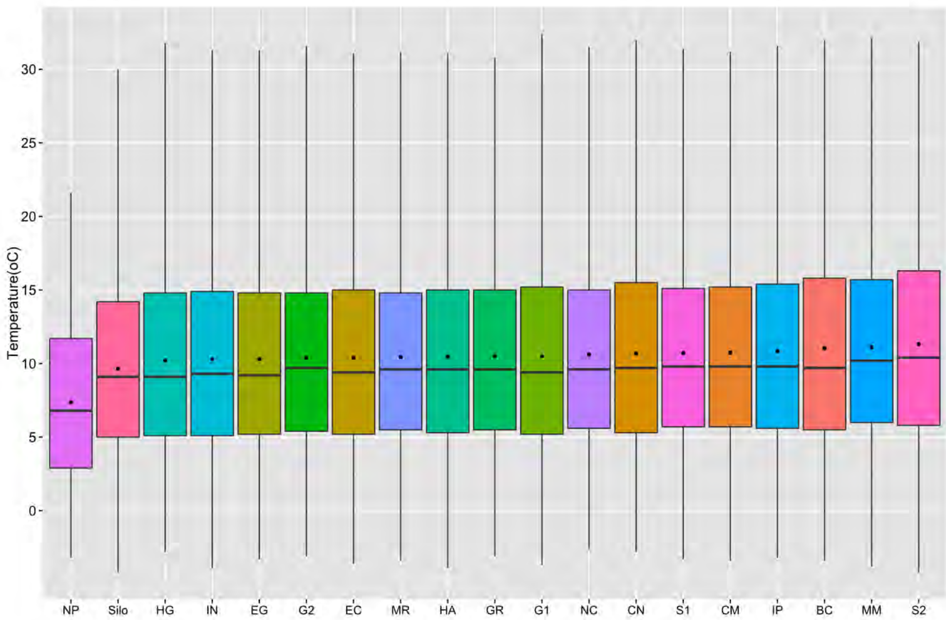


Figure 5.13 Distributions of daily minimum temperature: SILO and 18 forecast GCMs: Wagga Wagga

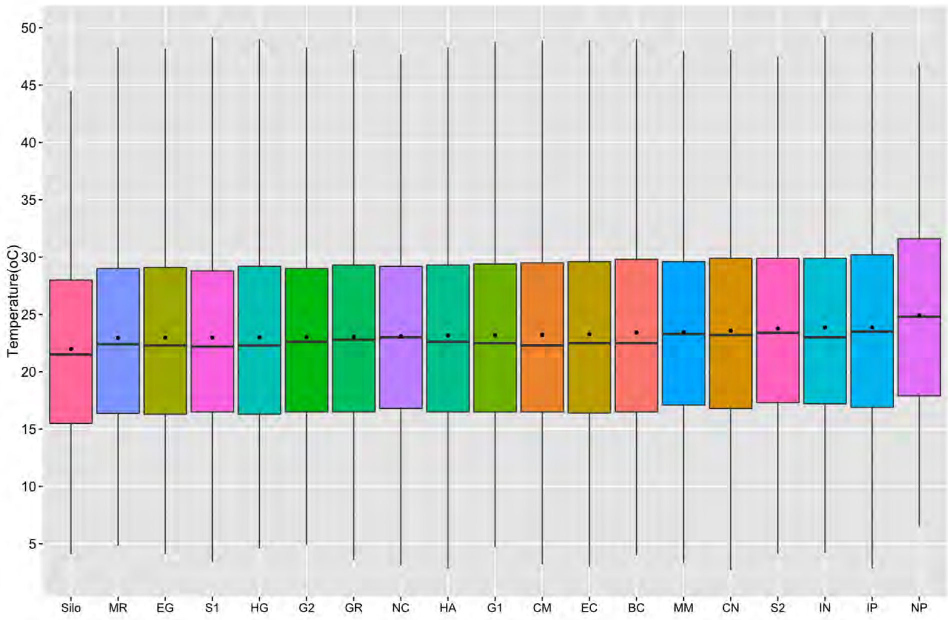


Figure 5.14 Distributions of daily maximum temperature: SILO and 18 forecast GCMs: Wagga Wagga

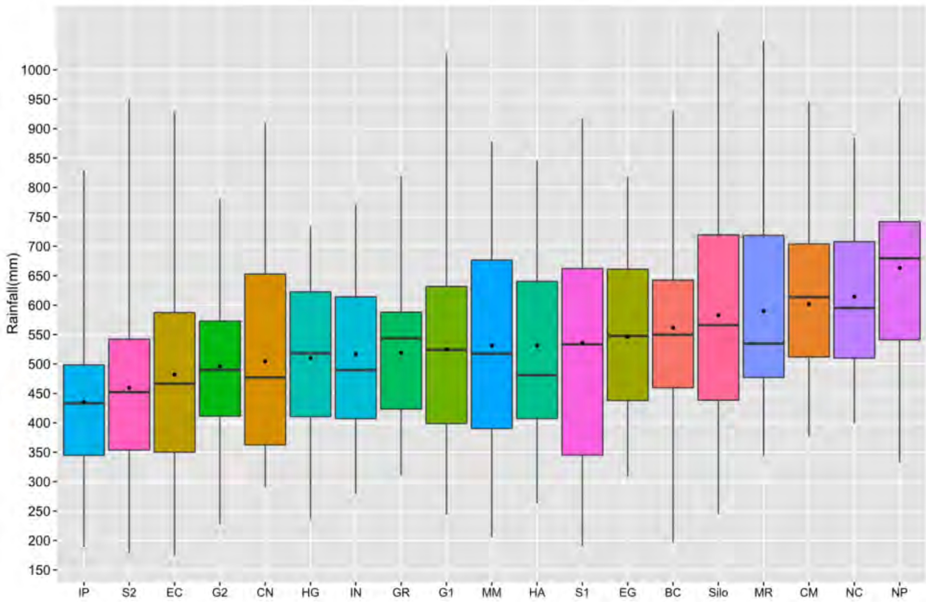


Figure 5.15 Distributions of annual rainfall: SILO and 18 forecast GCMs: Wagga Wagga

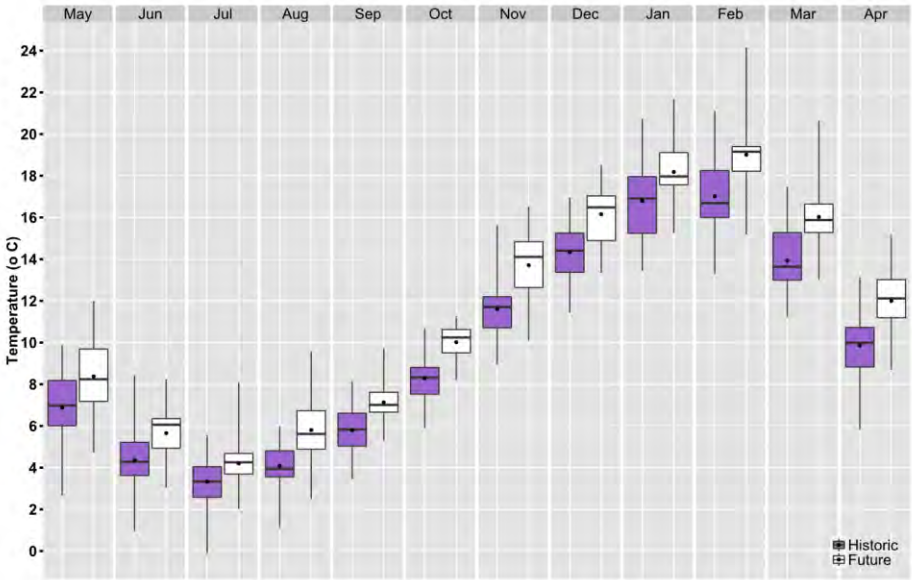


Figure 5.16 Distributions of monthly mean minimum temperature: SILO and S2: Wagga Wagga

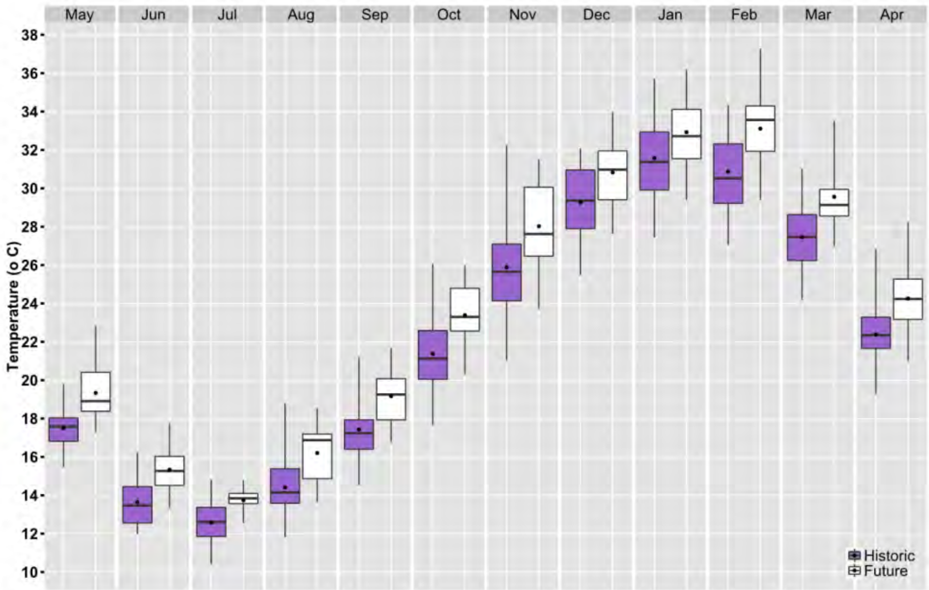


Figure 5.17 Distributions of monthly mean maximum temperature: SILO and S2: Wagga Wagga

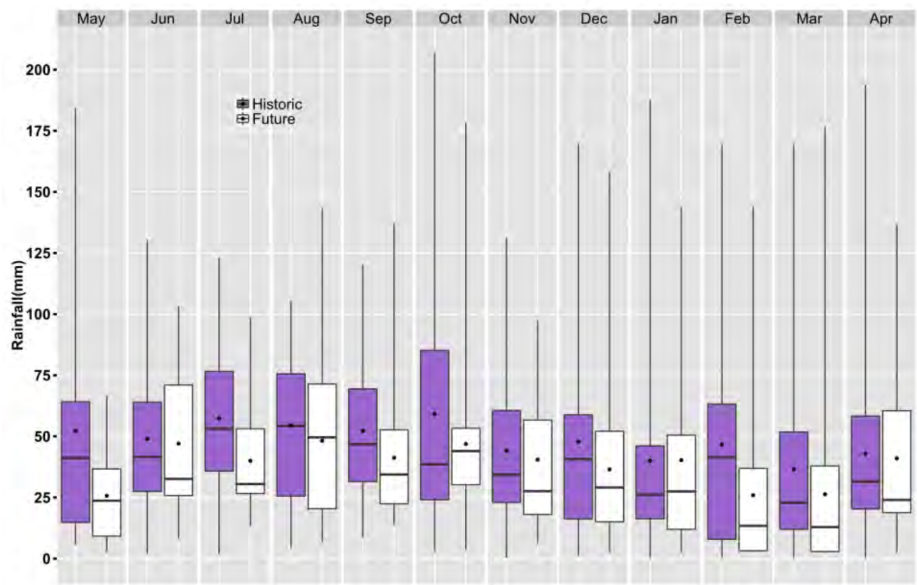


Figure 5.18 Distributions of monthly rainfall: SILO and S2: Wagga Wagga

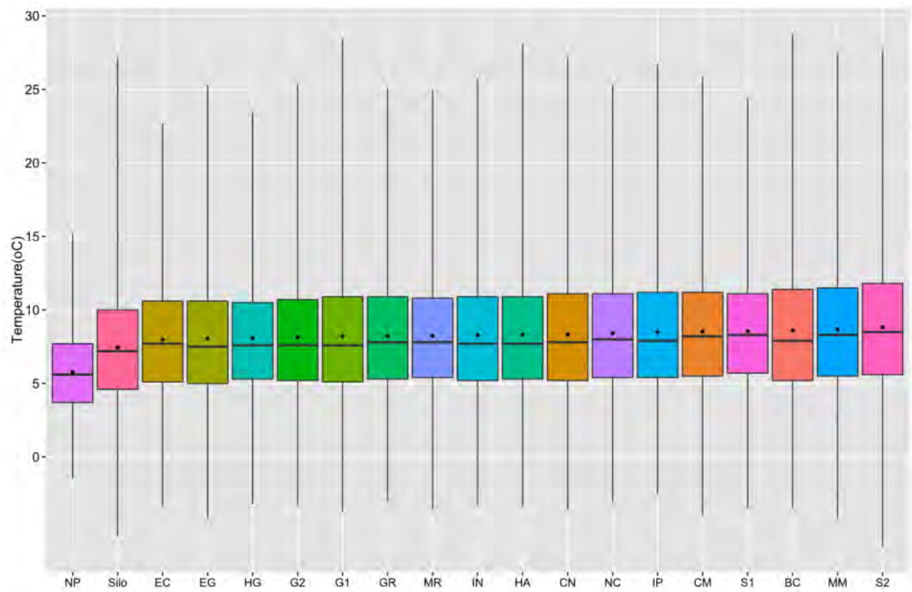


Figure 5.19 Distributions of daily minimum temperature: SILO and 18 forecast GCMs: Hamilton

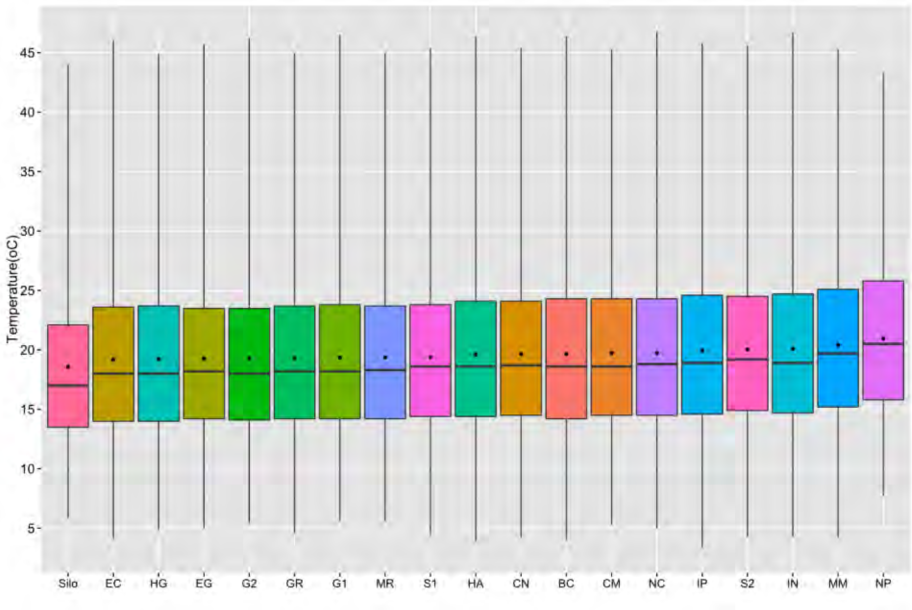


Figure 5.20 Distributions of daily maximum temperature: SILO and 18 forecast GCMs: Hamilton

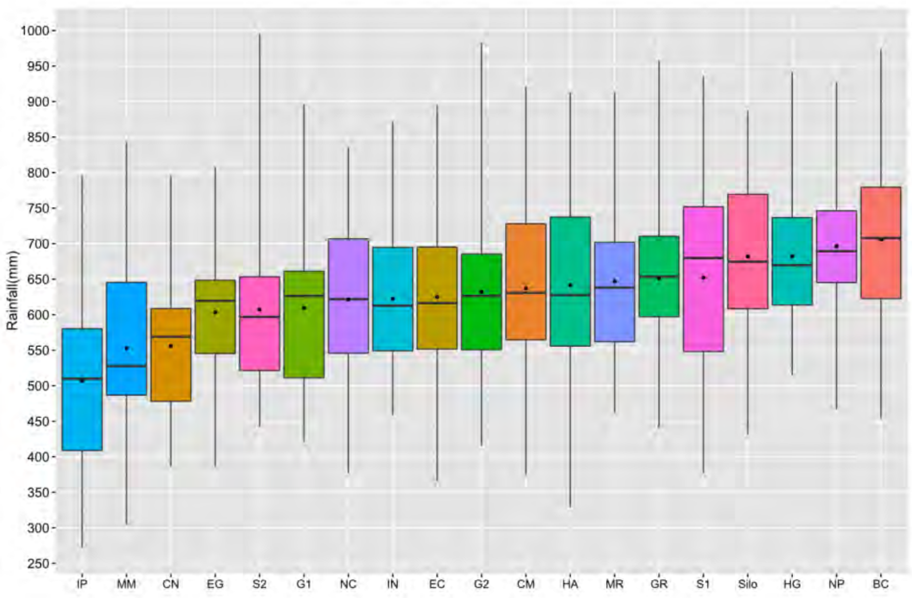


Figure 5.21 Distributions of annual rainfall: SILO and 18 forecast GCMs: Hamilton

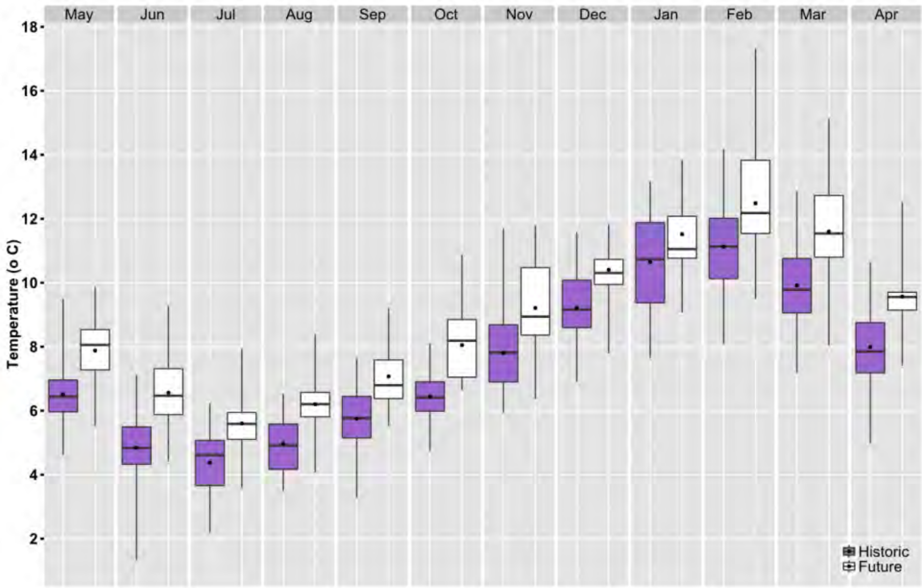


Figure 5.22 Distributions of monthly mean minimum temperature: SILO and S2: Hamilton

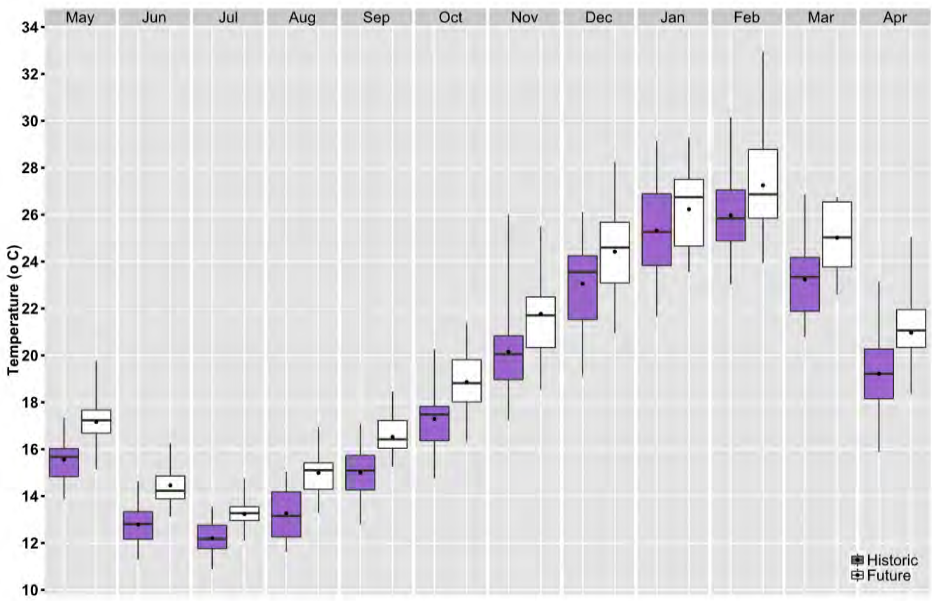


Figure 5.23 Distributions of monthly mean maximum temperature: SILO and S2: Hamilton

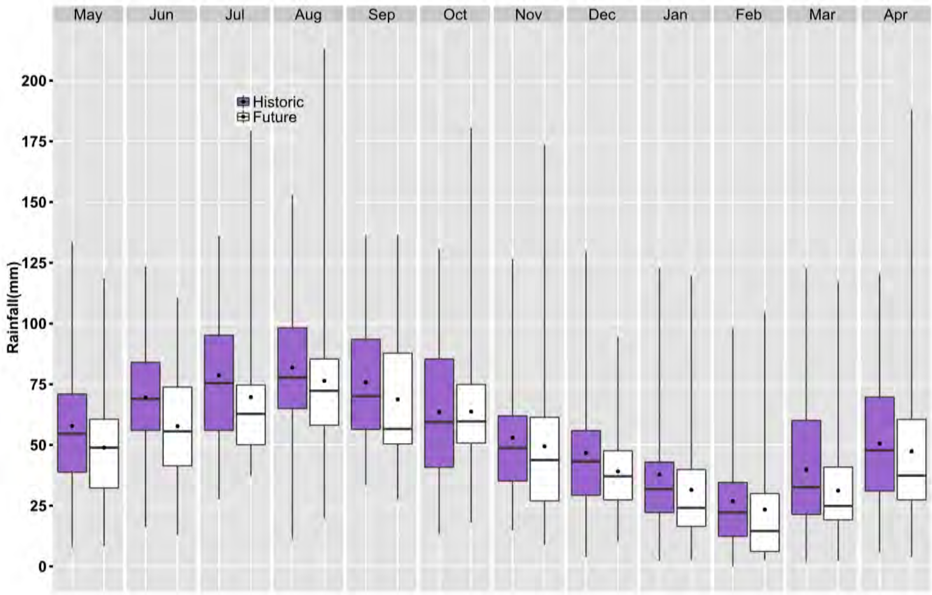


Figure 5.24 Distributions of monthly rainfall: SILO and S2: Hamilton

6. Biophysical modelling and plant responses to climate

Summary

This chapter contains results of biophysical modelling of plant responses (for crops, pastures and mallee trees) for the historical and future climate series presented in Chapter 5. A feature of the crop yields is that we present distributions of the yields (over 40 years of historic and 40 years of one predicted future). We compare these distributions visually to obtain an overall impression of the change, including downside and upside risk.

The pasture predictions were generated on a daily basis over each 40-year period; the data are 40-year daily averages of pasture production. These numbers were aggregated over the months because we are interested in the seasonal pattern of pasture supply, which is matched against the seasonal livestock demands in the whole-farm economic model. Hence we do not present box-and-whisker plots for monthly pasture production.

The tree biomass growth predictions were generated by a newly developed model, IMAGINE, which incorporates growth and regrowth patterns after coppicing every four years.

The crop yield results are interesting for the distributional changes over the 40-year periods studied (past versus future). Generally the crop yield distributions are lower under a future climate. In some cases there is increased variability in the predicted yield distributions and in others there is reduced downside risk. Such results have potentially substantial implications for regional farm management.

The results for pasture growth need to be more carefully considered and checked. This is a major research project by itself. For some locations and soil types predicted future pasture production is lower than in the past, while in a smaller number of cases there are indications that the future is not so dire. The pasture results depend on the rainfall and temperature distributions from Chapter 5 and some potential increases in pasture are explained by changes in seasonal rainfall patterns.

At Cunderdin the pasture production trends are lower over the whole year in the future compared to the historical case. At Katanning there is some indication of improved future production, more so for perennial than annual pastures. At Wagga Wagga pasture production is predicted to be substantially lower over the whole season for all species, with major implications for the farming system. But at Hamilton there is some indication that future perennial pasture production may be only slightly lower and, interestingly, there is some evidence of a shift in seasonal patterns to increased winter-spring growth at the expense of the summer-autumn period. The landholders interviewed in that region alluded to this shift and were confident that they could adapt to it.

When considering the predictions of mallee tree biomass yield we must remember that mallees are not currently grown in those locations (or anywhere else in Australia), so that a comparison of past versus future production is not relevant. The important question is whether the predicted future biomass yields and patterns of growth are likely to be economically appealing in a farming systems context, assuming that a local industrial processing facility would be established and a price for biomass that makes the activity potentially appealing to landholders. The average annual biomass yield in the future is 15.1

green tonnes (gt)/ha and we present the pattern of future growth in green biomass, with harvesting every four years.

6.1 Purpose

In this chapter results of the biophysical modelling are presented. These results have been developed using the climate series described in Chapter 5. These crop, pasture plant and tree biomass results are subsequently used in the economic analyses reported in Chapter 2.

6.2 Climate models used for developing plant responses

The biophysical models used to develop the results presented here were the Agricultural Production Systems Simulator (APSIM 7.3, McCown et al. (1996), Probert et al. (1998), Keating et al. (2003)) for crop yields. For pasture production, GrassGro (Donnelly et al. (1997), Freer et al. (1997), Moore et al. (1997), Clark et al. (2000)), and APSIM for tree biomass (Mendham et al. (2012)) models were applied.

The APSIM model simulates the development, growth, and final yield of several crops under prescribed management, as well as the changes in soil water and soil nutrient supply during the cropping season (Asseng et al. (2004), van Ittersum et al. (2003), Ludwig and Asseng (2006)). APSIM modules have been well tested in a wide range of conditions in Australia (Keating et al. (2003), Anwar et al. (2009), Wang et al. (2011)) and the model was verified as competent to simulate the crop growth and development, soil water and nutrition balance, and their interactions within a crop/soil/CO_2 system driven by daily weather data under different scenarios (Moore (2012), Oliver et al. (2009)).

The climate variables used in these predictive analyses were daily minimum and maximum temperature, daily rainfall and CO_2 levels. For CO_2 concentration the level implemented for future crop yield predictions was a linear increase from 380 in 2012 to 550 ppm by 2050.

6.3 Agricultural management and plant yield response modelling

When farmers make agricultural production decisions they must account for many interdependent factors. For instance, when planting a wheat crop, management factors or decisions to be considered include variety, sowing date, seeding rate, soil fertility status, and the presence of weeds and diseases. These factors will depend in part on previous management (including the past crop/pasture rotation), the status of the season, and future plans.

In modeling plant responses it is not possible to account for all these factors as direct inputs to the model. Rather a set of assumptions is made about the paddock status and these factors are included as parameter levels included in the productive models. The art of modelling includes an understanding of the agricultural system and developing a set of assumptions about the agricultural system status to enable prediction of yield responses that are reasonable for the purposes of analysis.

For the crop yield modeling, assumptions were made about normal farm fertilizer applications and sowing date and these aspects were included in the model. These assumptions were sensitive to the locations and soil types for this project. For pasture modelling an important management decision relates to the stocking rate for animals (which varies seasonally) since there are important interactions between stocking rate, pasture production and animal performance (e.g. expressed as liveweight gain and condition score). The GrassGro analyses were conducted for a range of stocking rates. In the economic analyses, data were adopted for the stocking rate which resulted in 80% of the highest gross margin in GrassGro. This level was used because most farmers do not manage their stock as tightly as a model assumes.

The crop yield results have been derived using APSIM. We present distributions of yields for wheat, barley, field peas, lupins and canola. However, development work on APSIM has been much greater for wheat and barley than for the other crops. In terms of the variability in yields for field peas, lupins and canola we have less confidence in the simulation results, especially when it comes to a predicted climate (Dr. Imma Farre, Department of Agriculture and Food Western Australia, personal communication).

The pasture modelling conducted for pasture plant responses in this project was not able to consider the potential impacts of a changed climate on animal physiology, especially temperature expressed as heat stress impact. Hence the predictions of plant responses using GrassGro need to considered with this caveat.

6.4 Soil types and land management units

The plant response modelling was conducted in the context of providing input data to the MIDAS and IMAGINE economic models at each location. Soils were classified according to the Australian soil classification (Isbell 1996). The whole-farm economic model (MIDAS) uses LMUs to describe the different parts of each representative farm. These LMUs are categorized in terms of soil types and suitability for local agricultural production activities. The plant response modelling was conducted for particular soils at each location. The soils used in the crop analyses are described in Table 6.1 and the soils used in the pasture analyses are given in Table 6.2.

Table 6.1 Soils used for crop analyses

Location	LMU	Soil description
Cunderdin	1	Acid loamy sand
	2	Clay
	3	Deep sandy duplex
Katanning	1	Clay acid over saline subsoil
	2	Duplex sand over light clay
	4	Deep sand
Wagga Wagga	2	Grey Vertosol
	1	Red Kandosol
	3	Red Chromosol
Hamilton	1	Sand
	2	Fine sandy clay loam over heavy clay
	3	Heavy clay

Table 6.2. Soils used for pasture analyses

Location	Soil description
Cunderdin	1. Sand, 2. Clay, 3. Duplex, 4. Loam, 5. Sand
Katanning	1. Acid saline sub, 2. Sandy duplex over light clay, 3. Deep sand, 4. Deep sandy gravel, 5. Deep loamy duplex
Wagga Wagga	Red Tenosol, Red Chromosol
Hamilton	Silty clay loam over clay

6.5 Results

The climate series used in this analysis were the historical data for the period 1971-2011 and the CSIRO Mk3.5 (S2) climate data for the period 2012-2052.

6.5.1 Crop yield results

At each location crop yields for wheat, barley, canola, field peas and lupins were developed for the soil types in Table 6.1.

6.5.1.1 Cunderdin

The Cunderdin crop yield distributions for historic and future are shown in Figures 6.1 to 6.3. In general the future yield distributions for wheat and barley appear to be lower with less upside. The future yield distributions for Field Peas appear to be slightly higher, and for Lupins the distributions are lower with less variability. The future yield distributions for Canola appear to be more variable.

6.5.1.2 Katanning

The Katanning crop yield distributions for historic and future are shown in Figures 6.4 to 6.6. In general the future yield distributions for Wheat and Barley appear to be lower with more downside risk. The future yield distributions for Field Peas appear to be slightly higher, and for Lupins the distributions are lower with less variability. The future yield distributions for Canola appear to be slightly more variable.

6.5.1.3 Wagga Wagga

The Tarcutta crop yield distributions for historic and future are shown in Figures 6.7 to 6.9. In general the future yield distributions for Wheat and Barley appear to be lower. The future yield distributions for Field Peas and Lupins are lower with less variability. The future yield distributions for Canola appear to be lower but less variable.

6.5.1.4 Hamilton

The Hamilton crop yield distributions for historic and future are in Figures 6.10 to 6.12. The future yield distributions for Wheat appear to be much less variable and for Barley much lower. The future yield distributions for Field Peas and Lupins are much less variable, especially for Lupins. The future yield distributions for Canola appear to be slightly lower but less variable.

6.5.2 Pasture production results

At each location pasture production predictions were developed for the soil types in Table 6.2. The GrassGro results presented here show seasonal (monthly) patterns of total available herbage (or feed on offer (FOO)) and average daily growth rates (ADG). To capture the seasonal nature of pasture growth the results presented here are for a single predicted series of each pasture measure. No distributions of pasture production (i.e. within months) were generated for this analysis.

6.5.2.1 Cunderdin

The Cunderdin pasture yield distributions for historic and future are shown in Figures 6.13 and 6.14. The different shape of pasture herbage mass between annuals and perennials for all soil types is seen in the graphs. In general the future FOO for the annual and perennial pasture is lower. For ADG there appears to be a substantial decrease in future growth over the historical trend on 2 soil types.

6.5.2.2 Katanning

The Katanning pasture yield distributions for historic and future are shown in Figures 6.15 and 6.16. The different shape of pasture herbage mass between annuals and perennials for all soil types is shown in the graphs. For both pasture types the future FOO is higher, with this trend more pronounced for the perennial pasture. For ADG there appears to be little change in future growth over the historical trend on any soil type. These increases in future FOO can be explained by the monthly rainfall trends in Figure 4.10, where the rainfall distribution is generally higher in the months of June, August, September, March and April.

6.5.2.3 Wagga Wagga

The Wagga Wagga pasture yield distributions for historic and future are shown in Figures 6.17 and 6.18. The GrassGro analyses were for one soil type and three pastures – annual ryegrass, lucerne and phalaris. At Wagga Wagga FOO and ADG are predicted to decline substantially for these pastures.

6.5.2.4 Hamilton

The Hamilton pasture yield distributions for historic and future are shown in Figures 6.19 to 6.22. The pasture graphs are presented for two animal systems, Merinos on ryegrass and on the Triple system, for three pastures, Banquet and Fitzroy Ryegrass and Sun Clover, on one soil type. At Hamilton perennial pastures are already part of the grazing system and the question is how they will perform in a future climate. In general the seasonal patterns for both FOO and ADG are slightly lower that the historic pattern. However, there is some shifting of the seasonal distributions with an increase in winter-spring pasture and a slight decrease in summer-autumn pasture.

6.5.3 Tree growth results

Results for predicted mallee tree growth under each climate scenario are in Table 6.3 and Figure 6.23. When considering the predictions of mallee biomass yield we must remember that mallees are not currently grown in those locations (or anywhere else in Australia), so that a comparison of past versus future production is not relevant. The important question is whether the predicted future biomass yields and patterns of growth are likely to be economically appealing in a farming systems context, if a local industrial processing facility was established and a market price was available for biomass.

Table 6.3 Whole-tree biomass yield of mallees expressed in green tonnes per hectare per harvest: future climate scenario: all locations

Harvest Year	Katanning gt/ha	Cunderdin gt/ha	Hamilton gt/ha	Wagga gt/ha
6	59	38	79	79
10	67	41	74	74
14	65	36	75	75
18	69	42	77	77
22	72	41	77	77
26	69	38	78	78
30	67	38	80	80
34	68	40	79	79
38	72	42	78	78
Total	606	356	696	696
Average	67	40	77	77
Stdev	1.4	2.4	3.4	4.4
cv	2%	6%	4%	6%

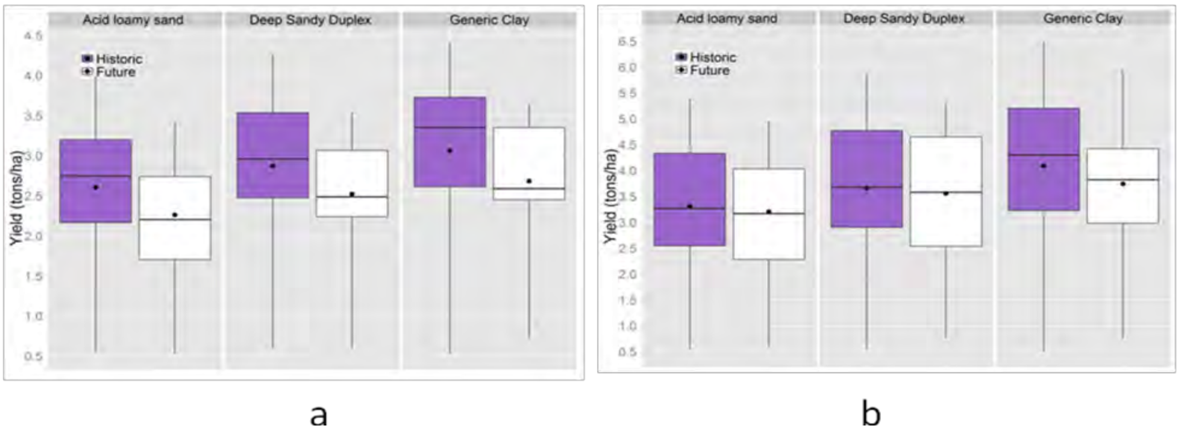
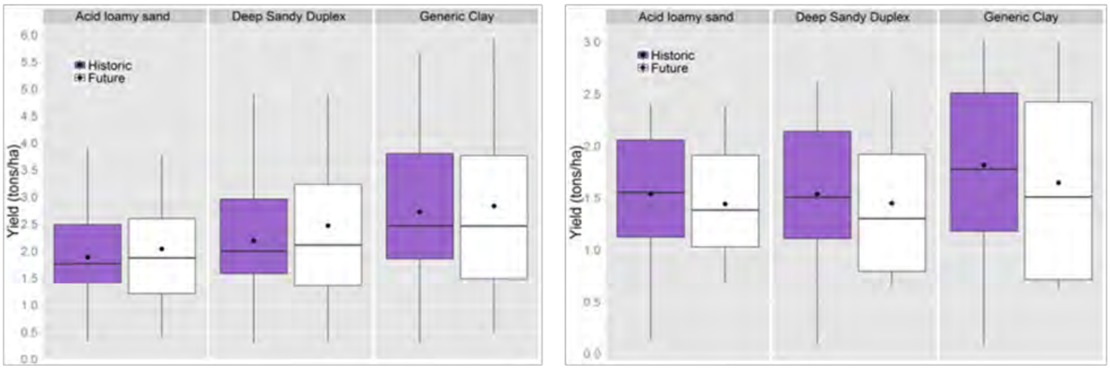


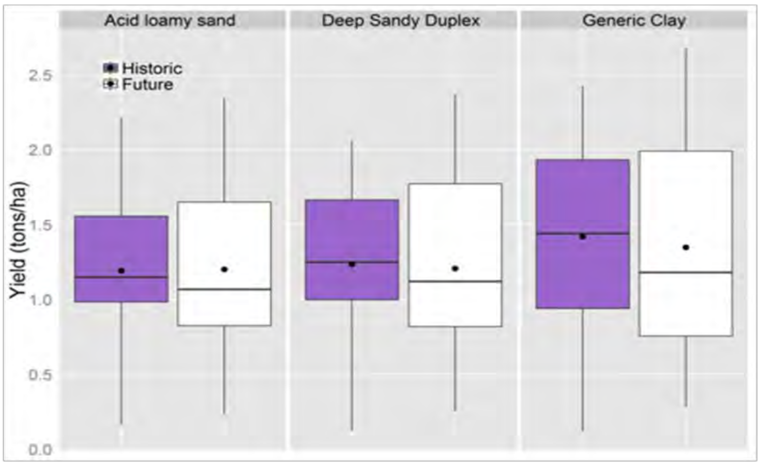
Figure 6.1. Distributions of wheat (a) and barley (b) yields by soil type: Cunderdin



c

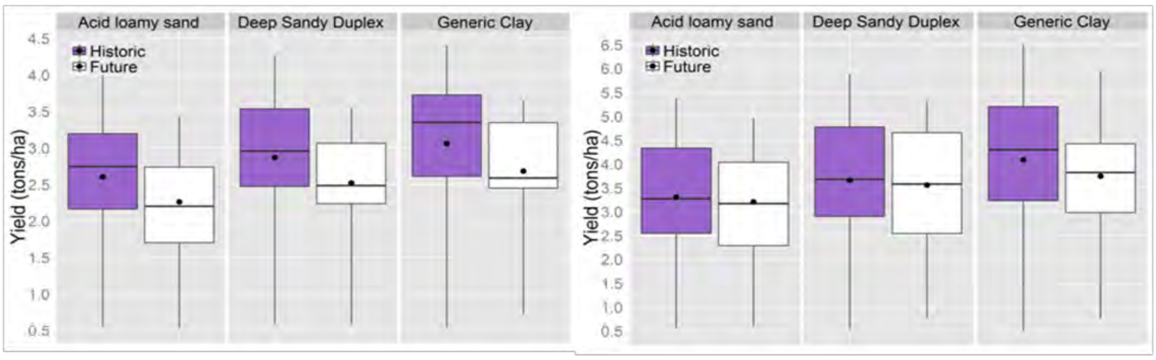
d

Figure 6.2 Distributions of field pea (c) and lupin (d) yields by soil type: Cunderdin



e

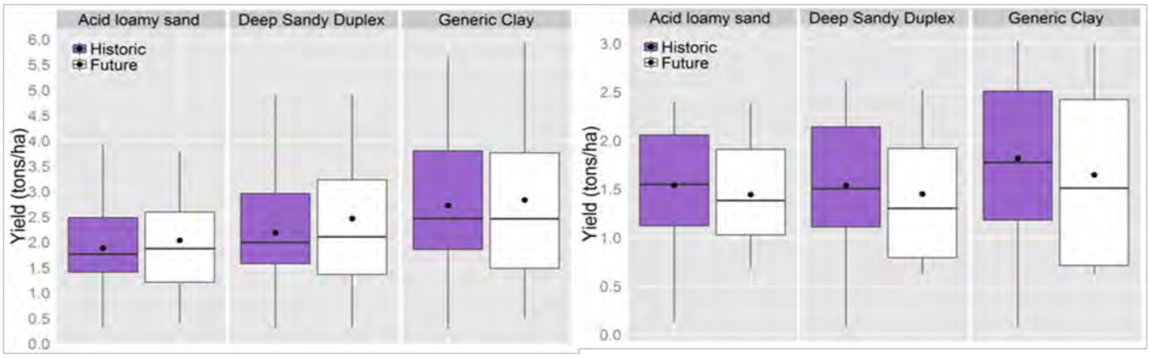
Figure 6.3 Distributions of canola yields by soil type: Cunderdin



a

b

Figure 6.4 Distributions of wheat (a) and barley (b) yields by soil type: Katanning



c d

Figure 6.5 Distributions of field pea (c) and lupin (d) yields by soil type: Katanning

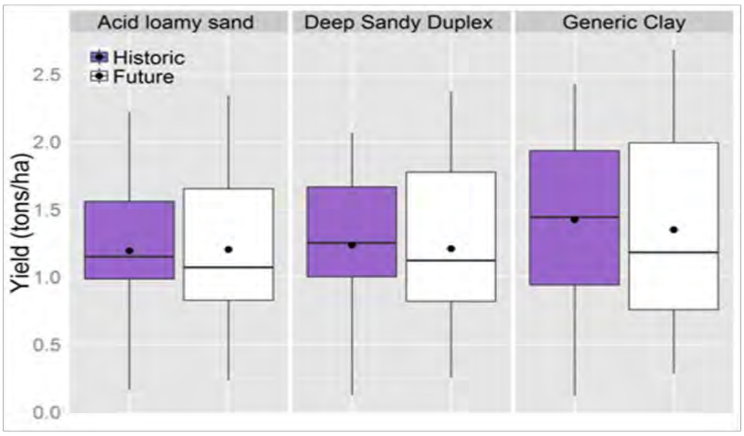


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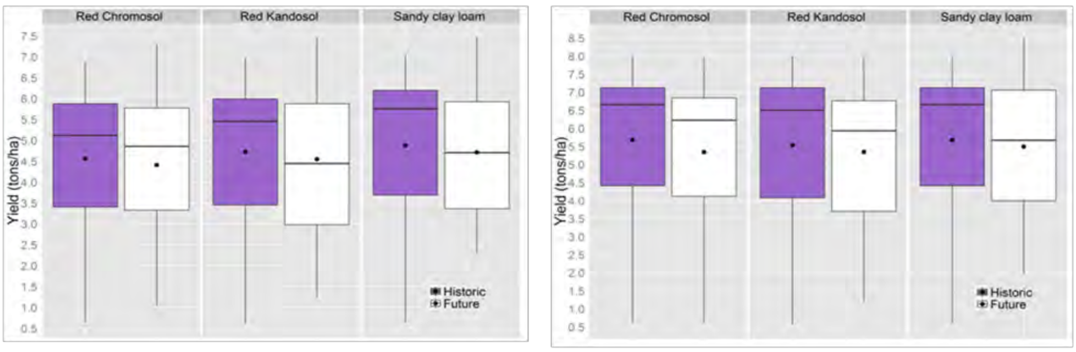
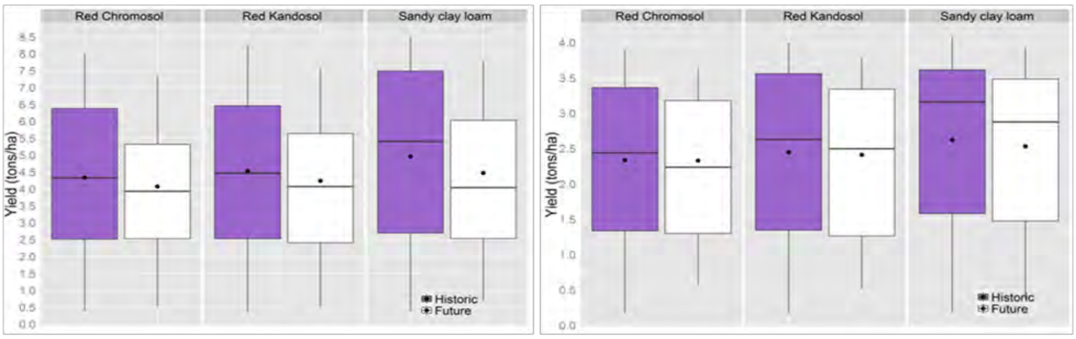
Figure 6.6 Distributions of canola yields by soil type: Katanning



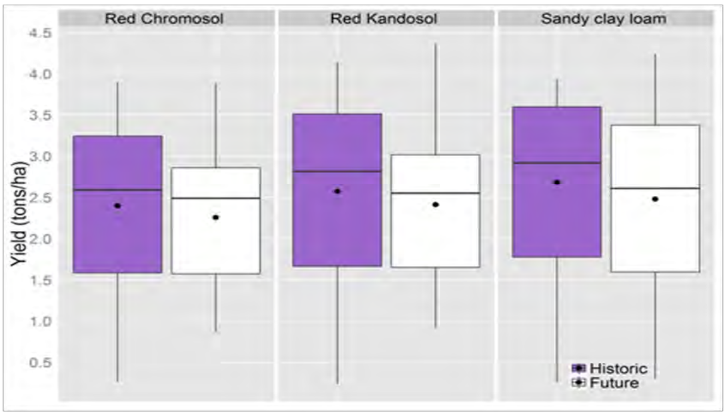
a b

Figure 6.7 Distributions of wheat (a) and barley (b) yields by soil type: Wagga Wagga



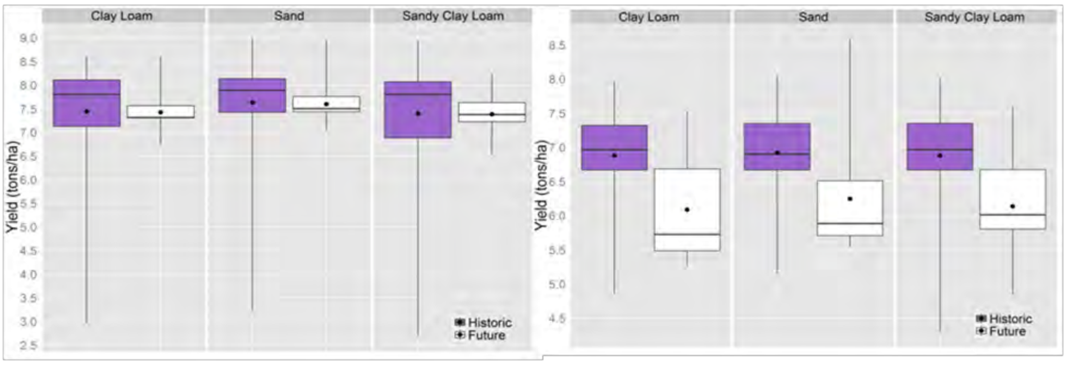
c d

Figure 6.8 Distributions of field pea (c) and lupin (d) yields by soil type: Wagga Wagga



e

Figure 6.9 Distributions of canola yields by soil type: Wagga Wagga



a b

Figure 6.10 Distributions of wheat (a) and barley (b) yields by soil type: Hamilton

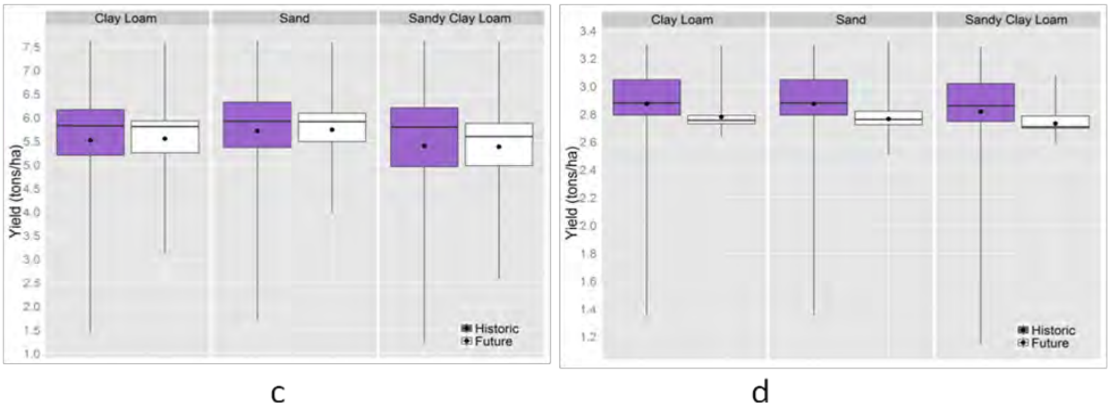


Figure 6.11 Distributions of field pea (c) and lupin (d) yields by soil type: Hamilton

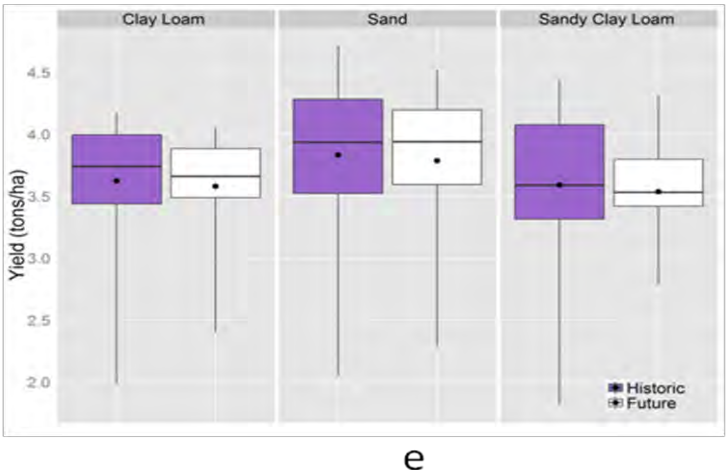


Figure 6.12 Distributions of canola yields by soil type: Hamilton

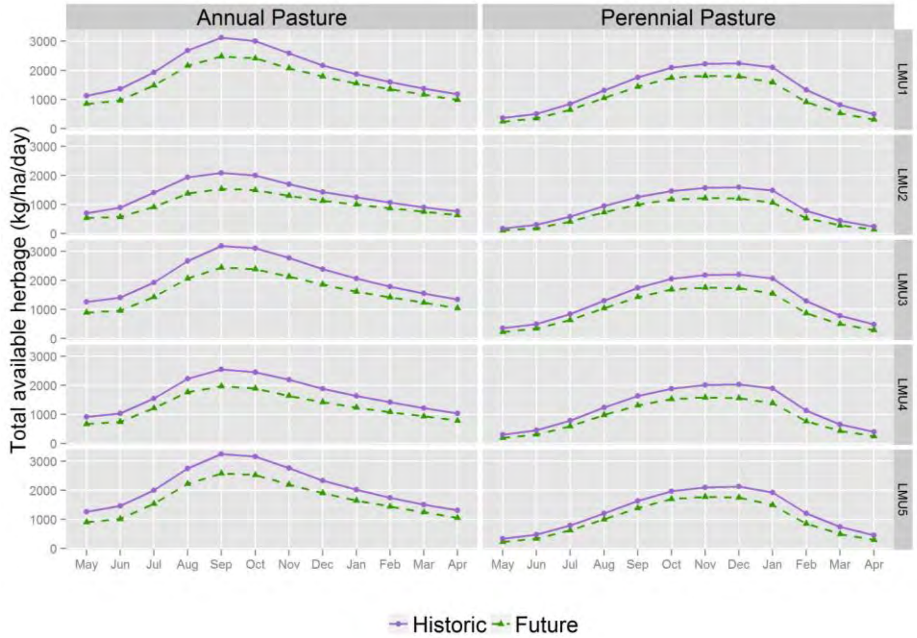


Figure 6.13 Total available herbage for annual and perennial pastures by soil type: Cunderdin

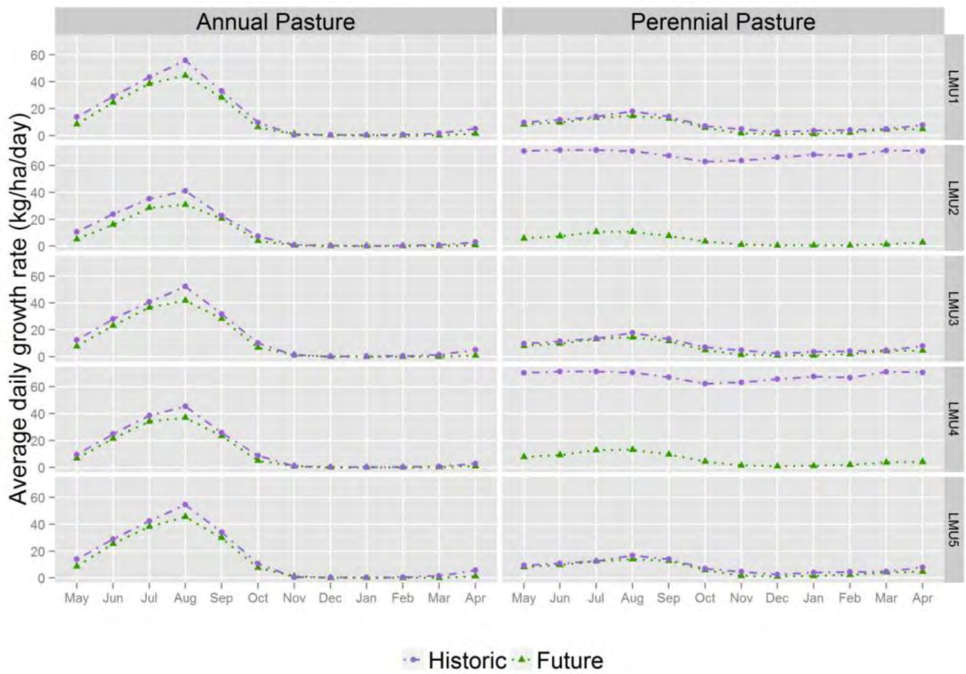


Figure 6.14 Average daily growth for annual and perennial pastures by soil type: Cunderdin

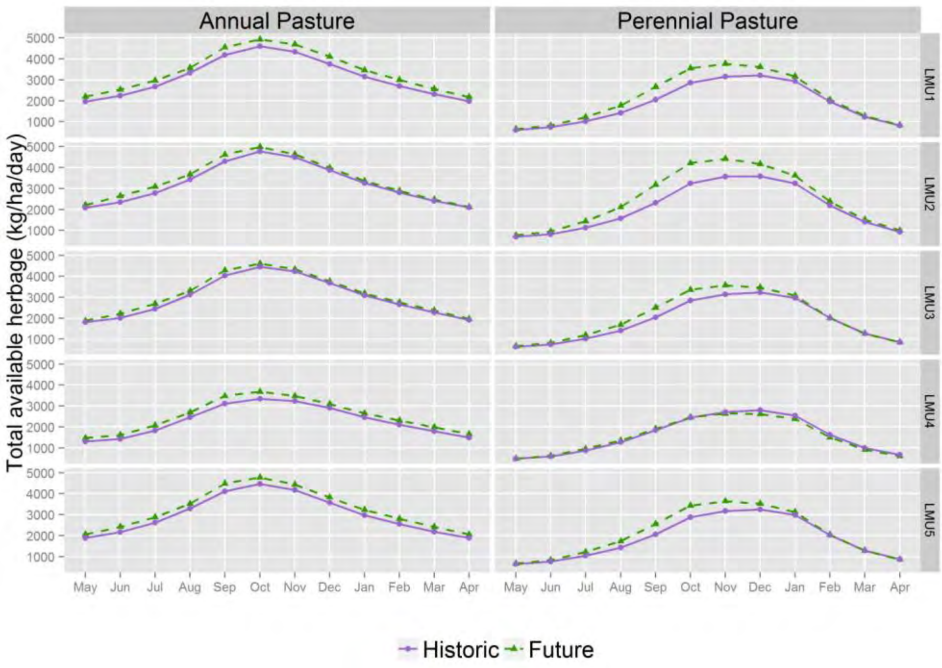


Figure 6.15 Total available herbage for annual and perennial pastures by soil type: Katanning

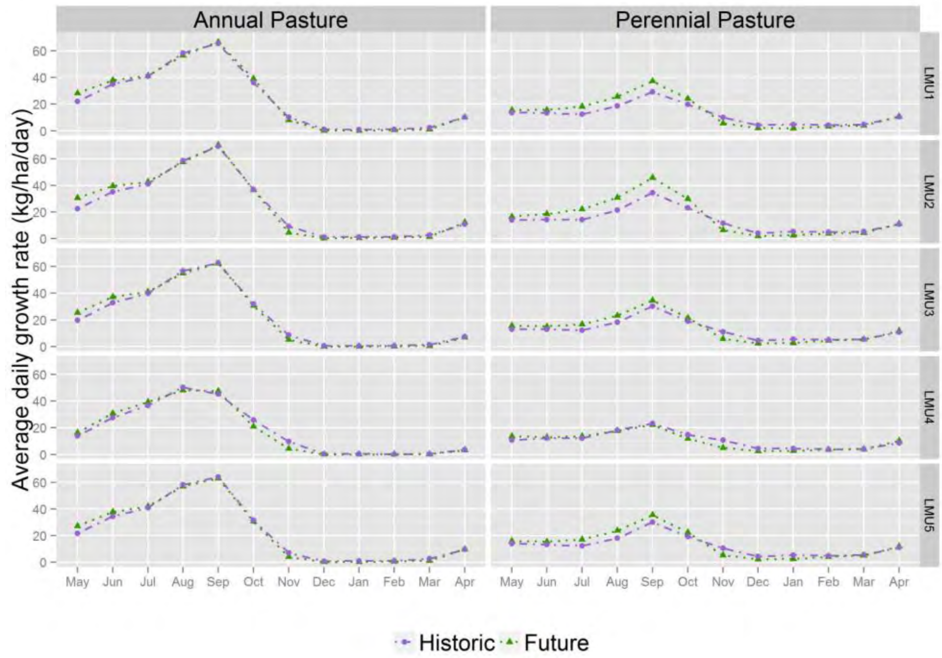


Figure 6.16 Average daily growth for annual and perennial pastures by soil type: Katanning

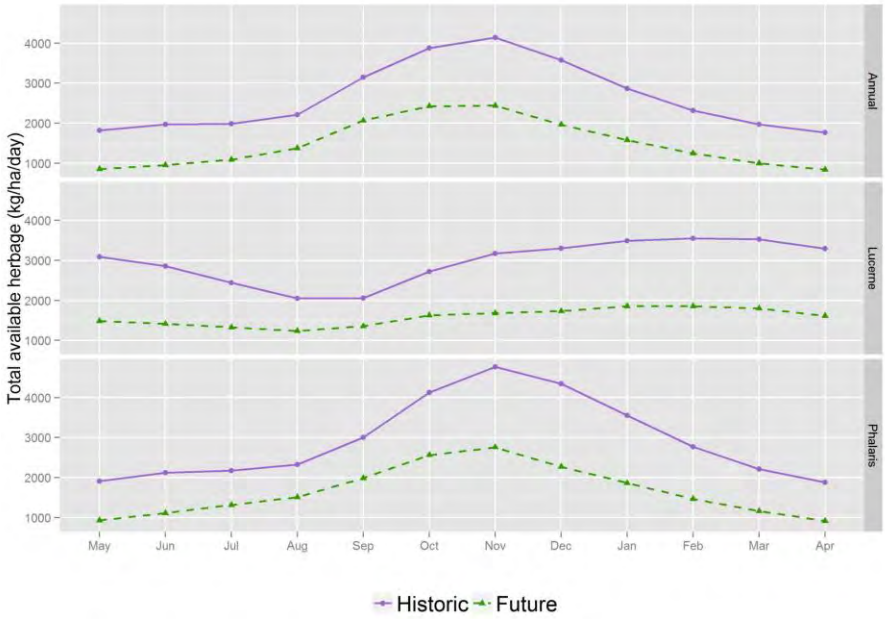


Figure 6.17 Total available herbage for annual and perennial pastures by soil type: Wagga Wagga

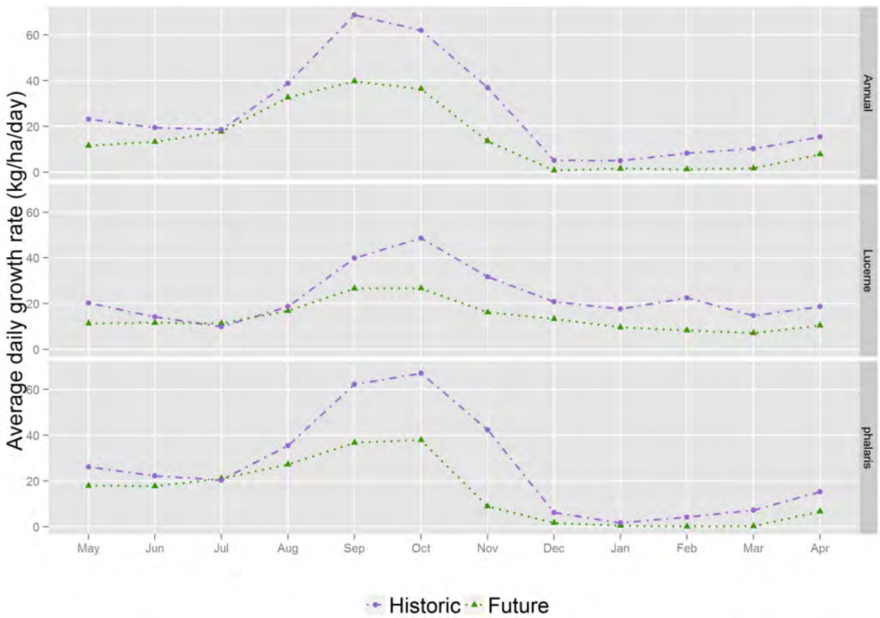


Figure 6.18 Average daily growth for annual and perennial pastures by soil type: Wagga Wagga

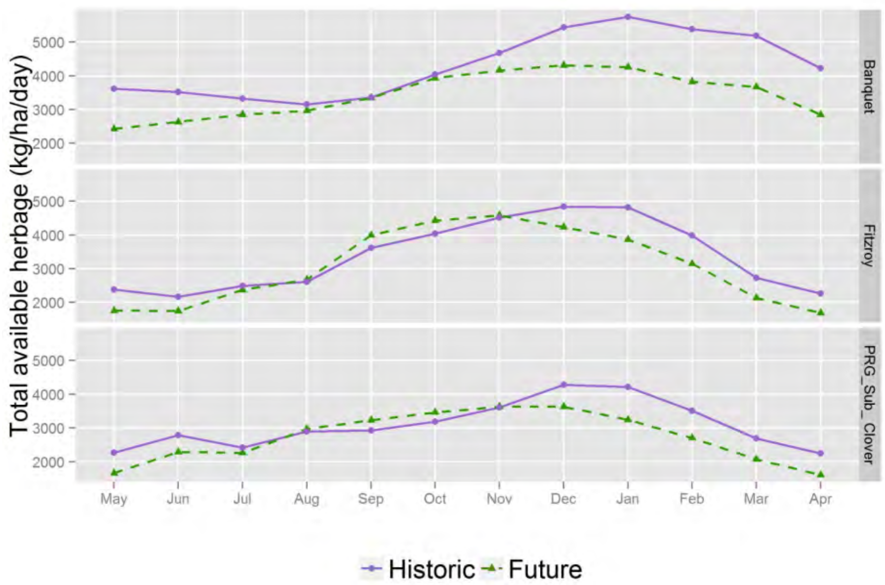


Figure 6.19 Total available herbage for annual and perennial pastures by soil type for Merinos on ryegrass: Hamilton

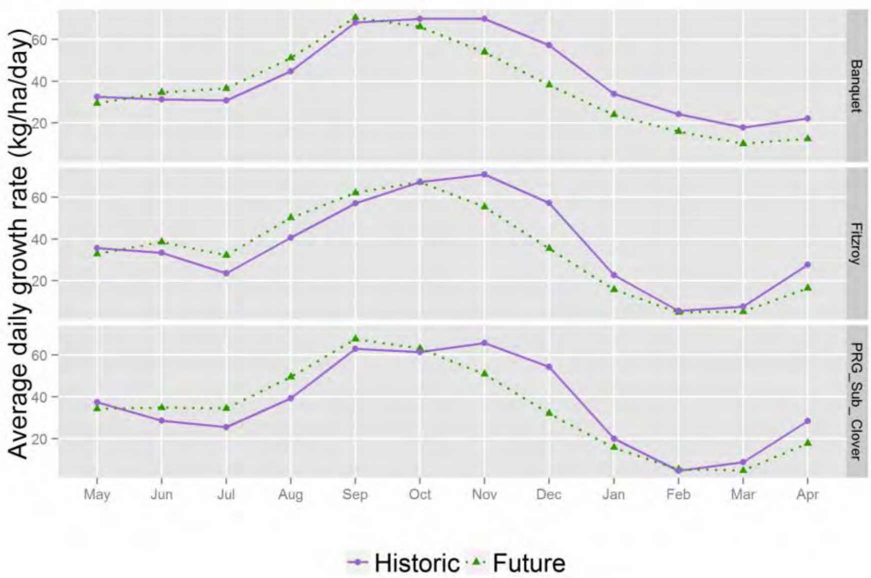


Figure 6.20 Average daily growth for annual and perennial pastures by soil type for Merinos on ryegrass: Hamilton

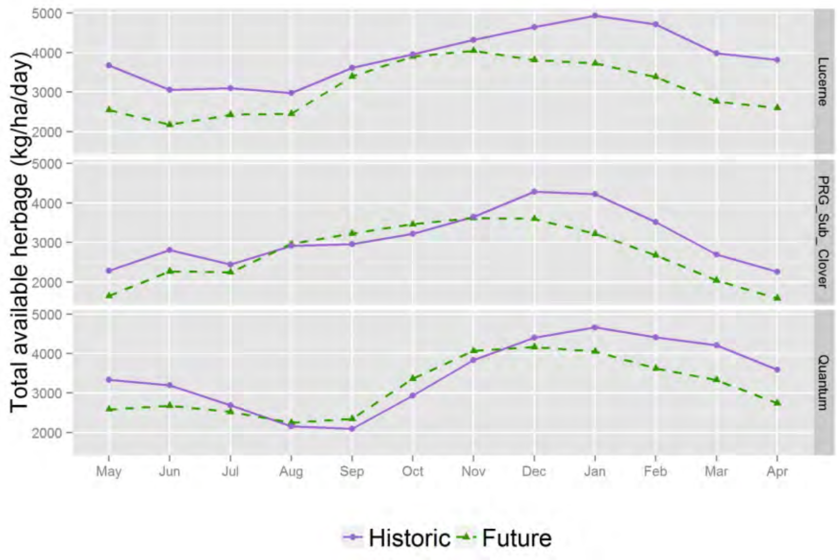


Figure 6.21 Total available herbage for annual and perennial pastures by soil type for Triple Merinos: Hamilton

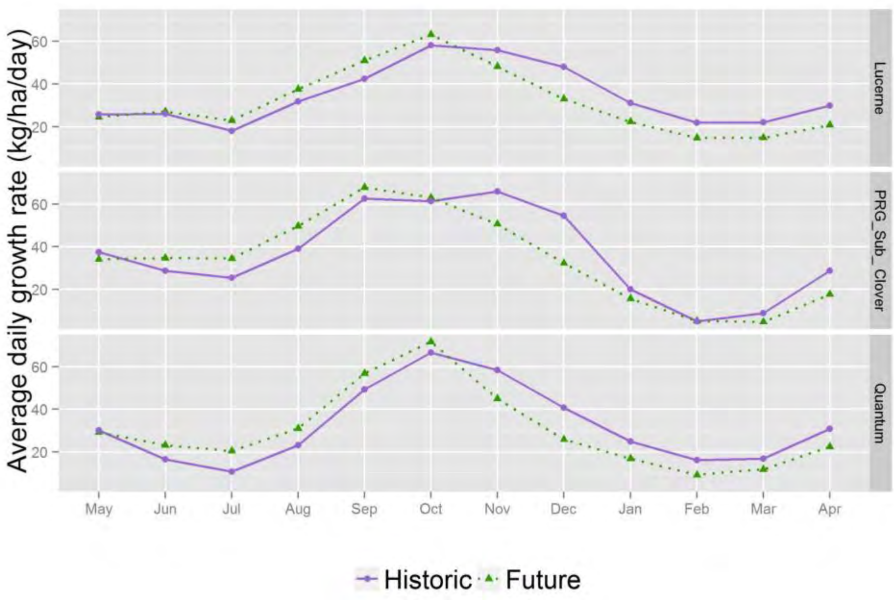


Figure 6.22 Average daily growth for annual and perennial pastures by soil type for Merinos on ryegrass: Hamilton

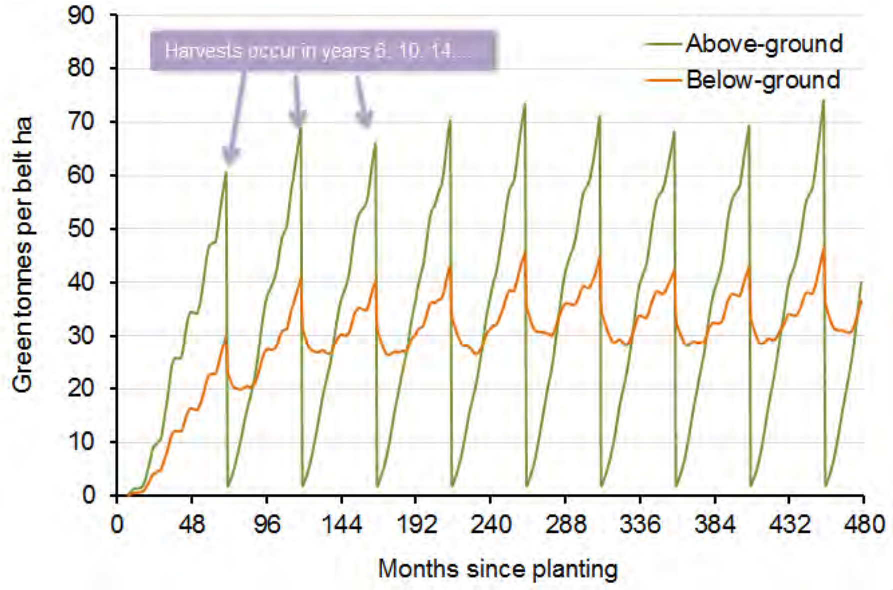


Figure 6.23 Simulated mallee growth above and below ground in 2-row belts of trees harvested periodically: example from Katanning on loamy deep sands: future climate scenario

7. Economic analysis of perennials in a changed farming climate

Summary

Two bio-economic models were used to analyze the optimal land use mix of farms as well as their profitability and cash flow. The first is the whole-farm optimization model, MIDAS. The other is IMAGINE, a model that is designed for field or paddock-level analysis. Each model has its role in the study and complements the other.

The MIDAS analyses presented here use a representative whole-farm approach to answer the research question of profitability with and without perennial plants and mallees for biomass, in an historical and likely future climate. The IMAGINE model is also used to investigate the same question at the farm enterprise (or paddock) level.

Usual caveats apply, in that although models provide advantages they have limitations as they necessarily require a number of assumptions, and they cannot fully represent reality and circumstances and conditions of all properties and the style and constraints of all farm managers. The models used in this study, in general, represent the farmer's main profit objectives and key operational constraints, especially of resource availability. But some aspects of the operational environment are necessarily simplified to allow tractability. Despite these limitations and simplifications models, these two farm economic analysis tools have proven extremely valuable in addressing important research questions of economic significance.

Another financial aspect of the decisions to change and adapt is cash flow. Analyses with IMAGINE show impacts on cash flow over time associated with perenniality and mallees for historic and predicted future climates.

7.1 Purpose

In this chapter we present the economic methodologies to answer the primary project question. This question is an evaluation of whether and the extent to which the use of perennial plant technologies can improve the capacity of dryland agricultural systems to adapt to climate change. This evaluation is conducted by modelling the impacts of currently achievable innovation with perennial pastures and trees, that are the research products of the FFI CRC, and testing their economic feasibility for large scale adoption under predicted climate futures.

Hence the focus of this project is on the likely economic responses within a farming systems context at each of the project locations. Whole-farm optimising models and paddock-level cash flow models have been used in this project.

7.2 Whole-farm optimising models

MIDAS, a mathematical optimisation model, was used in this study to assess likely whole-farm effects of changes in climate and plant responses. MIDAS stands for "Model of an Integrated Dryland Agricultural System". It is a steady-state linear programming model of a farming system, which accounts simultaneously for the biology and economics of the farming system (Kingwell and Pannell 1987). The model's objective function is profit maximisation, subject to managerial, resource and environmental constraints (Kingwell and Pannell 1987).

Profit is defined as net cash returns after non-cash costs (depreciation) and opportunity cost of capital (exclusive of land) are deducted. MIDAS is based on a typical (expected/average) season and excludes consideration of climate and plant variability and extreme climatic events.

MIDAS models are structured in equilibrium, meaning that production coefficients represent a time when production has stabilized, possibly after more than one rotational cycle. Dynamics are represented in the sense that production depends on land use and agronomic practices in the previous year, but not in the sense of tracking the move from one equilibrium to another. It is assumed that climatic conditions are 'average' every year.

For programming models such as this Kingwell (1996) has noted the importance of representing the farming system, with its array of production technologies, resources and enterprise alternatives, in some detail. Unless this occurs it is highly likely that specification errors will noticeably bias estimates of supply response.

The major strengths of MIDAS are its joint emphasis on biology and economics and its ability to address a range of whole-farm issues in a profit-maximizing framework. The issues include allocation of land to alternative enterprises, rotation selection, livestock flock structure and stocking rate, strategies for grazing and supplementary feeding, machinery size and pattern of use, and impact of limited finance on the optimal farm strategy.

MIDAS can also provide additional useful information such as the optimal rotations for each LMU and the size and management of sheep flock and other economic indicators including the marginal value of resources such as labour, finance, seeding capacity, and livestock feed in each of ten periods.

For a full description of MIDAS see Kingwell and Pannell (1987). Three versions of MIDAS were used in this study.

7.2.1 Marginal values for farm enterprises

Extra information is also available when an optimizing model is used to answer this type of research question. Because of the model structure (a resource-constrained farm profit model) which is used to maximize the economic objective, economic values can be determined for the last small amounts of land resource for each farm enterprise in the optimal solution. These can be termed the marginal value products (MVPs) of each activity (Paris (1991), Pannell (1997)) – they show the extra value that each farm activity contributes to the farm objective at the optimal solution. The MVP is also termed the shadow price of each LMU.

For each LMU the MVP of the optimal farm enterprise (or model activity) indicates the value added to the farm objective according to the soil and topography constraints, each LMU's area, and associated crop yield and pasture productivity assumptions. Changes in land use for each LMU, as climate and perenniality options are modified or added, can be explained by changes in the MVPs. That is, the MVPs indicate the economic incentives to change within each component of the farming system. They can differ substantially according to the type of soil resource and resulting agricultural productivity.

Consideration of MVPs associated particular model solutions provides a richness of explanation as to how farming systems constraints can determine the direction and magnitude of change in farm profits as new scenarios are considered. MVPs, which provide the marginal contribution to profit, are different from gross margin budgets, which indicate the average profitability of a farm enterprise.

7.2.2 Central Wheatbelt (Cunderdin) of Western Australia

This version of MIDAS is based on a typical farming system in the Cunderdin shire of Western Australia (Flugge and Abadi 2006). The area has a Mediterranean climate, with wet winters and dry summers. Farms in the region typically have a mix of cropping and livestock enterprises, with cropping generally more dominant. Broadly speaking, soils in the region consist of a mixture of deep sands and duplex soils (sand over clay, loam over clay). Farm size has increased in recent years and in 2012 was in the range of 3600 to 6800 hectares (Planfarm-Bankwest 2012). Central Wheatbelt MIDAS assumes a farm size of 2000 ha and consists of eight LMUs. A description of each LMU and area is in Table 7.1 (Flugge and Abadi 2006). Cropping options include cereals, grain legumes and an oilseed crop. Cereal crops include wheat, barley, oats and triticale. Grain legumes include lupins, field peas and other pulse crops. The livestock enterprise consists of sheep for wool and meat production. The pastures consist of volunteer annual grasses and improved pasture legumes such as subterranean clover and seredella. The percentage of total farm area selected for cropping is generally between 50% and 70%, depending on commodity prices. This level of cropping concurs with industry's management benchmarks reported in Planfarm-Bankwest (2012).

7.2.3 Great Southern Region (Katanning) of Western Australia

The Great Southern version of MIDAS represents a farming system in the Katanning/Kojonup shires of Western Australia. This area also experiences a Mediterranean climate. Rainfall in this region is higher than in the Central Wheatbelt. The average annual rainfall is between 500 mm and 600 mm. Most farms in this region have a mixture of livestock and crop, with livestock being dominant. Livestock in the region includes sheep and cattle; however merino sheep for wool production is most common. Broadly, the soils of the region are gravelly sands or sandy duplexes. In the Great Southern MIDAS the farm size is 1000 hectares consisting of five LMUs (Table 7.1). An average season has annual rainfall of 550 mm of which approximately 450 mm falls in the growing season (Young 1995). Wheat, barley, oats, lupins and field pea production are possible on all LMUs. LMUs 1 and 2 are relatively infertile and are normally not cropped. LMUs 4 and 5 are most suitable for agriculture.

7.2.4 Wagga Wagga/Tarcutta in New South Wales

A MIDAS version for Tarcutta was being developed from a version used in the Little River Catchment in the Central West of NSW (Bathgate and Hoque (2007), Bathgate et al. (2004), Finlayson et al. (2010)). The model was reviewed for its applicability and relevance to the economic analysis of the farms at Tarcutta. The model was found to be dysfunctional for the purpose of analysis due to its inaccuracies and for being out of date with respect to commodity prices, yields and inputs costs. The debugging and updating required to make it functional proved to be impossible in the time frame for the project. Consequently, MIDAS results are not presented for Wagga Wagga. However, the analysis of the economics of alternative land use systems in the Wagga Wagga region was conducted with IMAGINE. Several sources of information and data were used to inform the analysis and calibrate the model. These sources include information obtained from interviews with growers, farm consultants and experts used in conjunction with farm management and financial performance data from published benchmarks (Holmes and Sackett Pty Ltd. 2012).

7.2.5 Hamilton in Victoria

The Hamilton MIDAS was adapted from a version reported in Young et al. (2004). The model represents a 'typical' farm in the Hamilton region of south west Victoria. The total area of the farm is 1000 ha and is comprised of three LMUs, see Table 7.1.

This model was originally developed for the FFI CRC EverGraze® project (Mendham et al. (2012)) to analyse three pasture species or systems: 'Current', 'High Perennial Ryegrass' and 'Triple system of lucerne, tall fescue and perennial ryegrass'. Sheep flock types analysed were traditional merino wool, wool-meat merino, wool-meat merino self-replacing with terminal sire, and first cross ewes.

7.2.6 Soil types of each site

LMU descriptions and soil types are shown in Table 7.1.

7.2.7 Limitations of the steady-state optimisation framework

A limitation of the use of steady-state optimisation framework that underpins the MIDAS models is the assumption of continuous average weather-year conditions. This means that the analysis represents a steady-state single period equilibrium, and does not account for variations in price, cost or climate conditions across weather years, and how these might affect farm management and farm profitability.

7.3 Paddock-level cash flow models

IMAGINE is a model for evaluating alternative agricultural land use systems (Abadi and Cooper 2004). It offers an analytical environment for comparative analysis of land use change at a field level. Its purpose is to fill the modelling and analytical gap that exists between simulation models such as APSIM, which describe the growth of a crop, and whole-farm optimisation models such as MIDAS.

IMAGINE is a bio-economic simulation model and a land use change analysis tool for evaluation of alternative crop and pasture sequences sometimes with complex design, such as the case when mallees belts are integrated into crops and pastures. IMAGINE is designed for flexibility so as to permit analysis of land use sequences for any agro-climatic or edaphic zone. A range of concurrent land use activities can be specified for a block of land consisting of one or several farm paddocks. It is possible to allocate land to any sequence of cropping or livestock activities. Activities can include annual crops or pastures, perennial pastures and tree crops. They can be arranged in any spatial configuration such as belts, alley systems or blocks. Hence the user can test the performance of any temporal and spatial management sequence for any area of land over the long term.

The database of IMAGINE and its computational facilities are designed to allow representation of a broad range of agro-climatic or edaphic situations. In IMAGINE, the project life or evaluation period for a specified land use strategy, can range from one to 50 years.

Table 7.1 LMU descriptions in MIDAS

LMU	Area (ha)	Name	Description
Cunderdin			
1	140	Poor sands	Loose, white and pale yellow sands. Low moisture and nutrient availability.
2	210	Average sand-plain	Yellow sandy. Cereal yields are limited by moisture and nutrient availability.
3	350	Good sand-plain	Produces high to very high cereal, lupin and pasture yields in most years.
4	210	Shallow duplex soil	Hard setting, heavier, grey to brownish soils. Good moisture and nutrient availability.
5	200	Medium heavy	Above average quality soil suitable for cereals, lupins and pasture.
6	200	Heavy valley floors	Produces good cereals, field pea crops and medic based pastures.
7	300	Sandy surfaced valleys	Suitable for cereal and pasture.
8	390	Deep duplex soil	Generally a productive soil with good moisture and nutrient availability.
Total	2000		
Katanning			
1	100	Saline soils	Shallow saline soils over heavy gleyed or mottled clay.
2	150	Water logged soils	Deep sands often waterlogged over grey gleyed clay.
3	50	Deep sands	Deep sands but not waterlogged over mottled clay.
4	500	Sandy gravels	Gravels and sandy gravels to 500 mm over clay or gravelly clay.
5	200	Sandy loams	Sandy loam, loamy sand over clay. Rock outcropping in landscape.
Total	1000		
Hamilton			
1	200	Low lying	Clay soils in lower slopes that are often waterlogged
2	600	Slopes	Moderately drained loams in the mid slopes
3	200	Crests	Well drained gravelly soils at tops of hills
Total	1000		

IMAGINE can report the financial consequences of selected management strategies as tables and charts. This allows the user to evaluate existing, emerging and prospective crop rotations or agroforestry systems against conventional farming systems. Sensitivity analysis features built into IMAGINE allow the user to evaluate these options over a wide range of yields, costs, prices, investment strategies and on-site benefits.

The modular data structure enables capture and storage of a range of variables that may vary overtime. Key inputs, such as a rainfall, commodity prices and costs, can be defined as data that can be drawn from two sources. One source may be observed historical records of seasonal variables. The other source may be user defined probabilistic distribution of variables. It is also possible to trend the distribution of the variables so as to allow for decay or growth trend in variables that may be distributed according to a specified mean and a standard deviation. It is also possible to generate the growth and yield data externally, using physiological models such as APSIM and GrassGro, and import their outputs into the crop growth module of IMAGINE (e.g. as a time series of yield of a crop such as wheat).

Data files containing information about crops, land use and management regimes can be saved for future reference and for comparison. Here, crops are broadly defined and they include pastures for livestock grazing as well trees that may grow biomass, timber and carbon. IMAGINE can report the consequences of selected management strategies as tables for charting and summaries. Output data from all simulations may be exported to an MS-Access data files for further query and analysis. This allows the user to easily evaluate historical, existing, and prospective new land use sequences or rotations against alternative land use sequences. It removes the need to develop individual spreadsheet versions of rotations, thus enabling the user to focus on analysis instead of spreadsheet model development with complex data structures, formulae or functions.

Sensitivity analysis features built into IMAGINE allow the user to evaluate options over a wide range of yields, costs, prices, investment strategies and on-site benefits.

Some other distinguishing features of IMAGINE include:

- Integration of annual as well as perennial plants in land use sequences. Perennial plants may be trees, shrubs and pastures, in short or long rotations with agriculture;
- Allowance for various spatial configurations and layouts of crops, such as belts and alley farming systems or block plantings;
- Allowance for various temporal sequences of a crop with other crops or pastures - for instance the effect of a legume crop on a subsequent cereal crop;
- Multiple harvest options, for example coppicing tree types such as mallee;
- Facility for analysis of trees with products other than timber – for instance biomass, carbon sequestration, oil, fruit, and forage;
- Temporal and spatial interactions between woody perennials and agricultural crops and pastures;
- Sensitivity analysis to help identify economically important parameters. The ability to run the model several hundred times, if necessary, to generate a distribution for values of key outputs enables the user to test the robustness of the results to uncertain inputs variables; and
- Features allowing users to save and retrieve input and outputs data.

IMAGINE's outputs include financial/economic data as well as physical and biological data such as rainfall and yield of crops. Its outputs can be used to compare profitability and cash flow of the alternative land use systems. This enables estimation of the equivalent annual value for comparison of returns from land use rotations and sequences of different lengths, which overcomes the common difficulty of comparing an agroforestry projects with agricultural rotations.

The model can be used to evaluate several scenarios and situations that may realistically occur and impact on commercial viability of a specific land use sequence. Using the model to conduct scenario and sensitivity analysis enables the analyst to test the robustness of land use strategy and give an indication of how resilient the analysis is to uncertainty in the environments, situations and markets being analysed.

Financial analyses using IMAGINE were conducted at all four project sites. The LMUs used in the Wagga Wagga version of IMAGINE are shown in Table 7.2.

Table 7.2 LMUs in IMAGINE: Wagga Wagga

LMU	Area (ha)	Name	Description
1	200	Red Chromosol	Red Chromosol (Petroferric)
2	600	Grey Vertosol	Grey Vertosol
3	200	Red Kandosol	Red Kandosol
Total	1000		

7.3.1 Financial measures

Financial measures developed from the IMAGINE results are net present value (NPV) , annual equivalent value (AEV), the minimum and maximum values of a cash flow over a period of time, and the standard deviation and coefficient of variation.

Discounted cash flow analysis was used to calculate the NPV using a discount rate of 7%. However, in calculating NPVs for land management scenarios and strategies, it is important to choose the same project life for each project. To handle the issue of comparing projects with different project lives an extension of the basic NPV model called equivalent annual returns (AEV) was used. The AEV method answers the question of what amount is received each year for 40 years, from two alternative land uses, that is equivalent to receiving the NPV of the two alternatives whose life is four decades. The AEV is calculated for each scenario (agriculture and the mallee crop) and the land use activity with the higher AEV is preferred. Measures of risk (variation in cash flow) can also be calculated as shown by the standard deviation and coefficient of variation of the income streams. Costs and prices have been kept constant in these analyses in order to discern the impact of climate change.

7.3.2 Translating pasture simulation data into cash flow analyses

In this study we applied the grazing systems modeling tool ‘GrassGro’ (Donnelly *et al*. 1997; Freer *et al*. 1997; Moore *et al*. 1997, Mokany *et al.* 2010) to examine how changes in climate affect sheep grazing systems based on annual pastures and perennial pastures.

GrassGro is a process-based model of grazing systems within which historical daily weather data drives models of soil moisture, pasture growth and animal production, with associated expenditure and earnings also calculated.

We applied GrassGro to grazing enterprises typical of the four sites that are the focus of this project. A simulation experiment was conducted with GrassGro for each of the scenarios and the resulting sheep flock management data were used to conduct the bio-economic analysis for each simulation run to produce the long-term cash flow and interaction effects between crops, pastures and trees.

We used historical climate data and data based on S2 GCM to conduct simulations of the sheep enterprises on the four project locations to obtain the likely responses of pastures and livestock to climate change and availability of perennial pastures and presence of mallees.

At each site we considered a sheep enterprise types typical of the region.

A site- and enterprise-specific set of stocking rates was simulated so as to incorporate the key biological and economic factors of interest. In each case peak gross margin ($/ha) occurs at a certain stocking rate and the stocking rate was then determined that would give 80% of the peak gross margin. This was considered to more realistically represent where a risk-averse farmer would be operating.

All simulations were run over the historical and future climate time series data (1971-2011) and (2012-2052) using climate data as described in Chapter 5.

Version 3.1.1 (3.2.5 for Hamilton, Cunderdin and Katanning) of GrassGro was used in this study. The user interface to this version of GrassGro has been substantially modified from that described by Moore et al. (1997), with the objective of making it easier to use the underlying biophysical models to systematically analyse management questions. The attributes of a specific grazing enterprise are described as a 'farm system' in GrassGro. A farm system is composed of ~20 'components', each of which describes a portion of the biophysical (climate, soils, pastures, livestock), managerial (e.g. stocking rate, reproductive management) or financial subsystem under consideration.

Once a farm system has been described and checked, GrassGro is used to execute 'analyses', which are simulation experiments in which one or more components of the farm system are systematically varied. On completion of the simulations comprising an analysis, a template is used to generate a summary report that contains graphical and/or tabular comparisons of the simulation results. The new user interface of GrassGro greatly reduces the amount of information redundancy and manual processing of results required to draw conclusions from simulation modelling. In this study, for example, we were able to specify, execute and summarise a large set (hundreds) of simulation runs based on specified farm systems and the associated report templates.

7.3.3 Background information for Wagga Wagga

Sheep production in Wagga Wagga is on a mixture of annual and perennial based pastures. McDonald and Orchard (2010) estimate that in Wagga Wagga annual pastures consisting of sub clover/ryegrass that are well fertilised can sustain winter stocking rates of 5–10 DSE/ha. Sub clover/ryegrass pastures complemented with lucerne pasture and fertilised with superphosphate can carry 9–15 DSE/ha. This is supported by McEachern and Francis (2013). A budget representing the most common sheep production systems, developed for this south-east region by NSW DPI (2011), indicates a gross margin (excluding overheads) of $366 per winter grazed hectare after deducting variable costs of $222 per hectare consider average stocking rate of 10 DSE/ha.

McEachern and Francis (2013) report that among the growers in their benchmarking group there is a range of 1.5 to 3 DSEs per winter gazed hectare per 100 millimeter of rainfall. Consequently, the region tends to have winter stocking rates of between 6-12 DSE/ha.

The analysis used here drew heavily on assumption used in the budget of NSW DPI for this region, and the benchmarks reported for south east NSW and north east Victorian sheep enterprises published in McEachern and Francis (2013), Tocker and Berrisford (2011). We have used similar assumptions regarding weaning percentages, death rates and growth rates to determine sale numbers and costs. The analysis is based on well-maintained pastures with production levels achievable by most producers, given good management practices and sufficient planning. Additional costs associated with purchase of additional sheep are included as are overhead costs. Fixed costs in the livestock enterprise modelled here add up to $112/ha.

Because it is extremely difficult for growers to accurately predict future prices, growth rates and feeding costs, to name a few of the variables, we used GrassGro to simulate the production of pasture and the attendant livestock. The livestock data along with information for supplementary feeding, attribution of each paddock's pasture to daily metabolisable energy requirements of each sheep class and their condition score at the time of sale were all used in analysis with IMAGINE to calculate the cash flows. In livestock enterprises the key to profitability is maintaining a simple system that matches feed supply with feed demand, and optimizing stocking rate. Careful timing of lambing and calving is important to ensure that feed is not limiting in the majority of years. Also critical is timing of sales so that weight gains occur during the low cost period of high feed supply and high feed quality (McEachern and Francis (2013)).

For livestock enterprises, production is determined by winter stocking rate per hectare which in turn is heavily dependent on the seasonal rainfall. Winter stocking rate decisions of growers are predominantly based on long term rainfall, not on the annual rainfall, most of which is still to come when decisions on stock numbers are being made (Tocker and Berrisford (2011)).

Robertson (2012) found that stocking rates for Wagga Wagga estimated by simulation modelling using GrassGro are several DSE/ha higher than those observed among farmers in that region. Robertson (pers. comm.) confirmed that there are several reasons why modelled stocking rate differ from those for real farms. Most farms operate well below optimum stocking rates due to limiting factors in the management of the system such as the type of sheep enterprise, differences in lambing time and lower pasture production than that estimated by a simulation model.

Simulation modelling is often based on good pasture sward composition, but observations of farms indicate that many pastures aren't as good as those in the models and would not be capable of carrying the optimum stocking rate indicated by the model. Minor factors that may also affect the difference between estimated and observed stocking rates are the number of lambs that are sold may well be higher than observed – average lambs marked per ewe joined is only about 80%.

In simulation models mortality of lambs is lower than observed because although the model accounts for chill index, it does not account for behavioral factors which lead to death among lambs. Mortality of weaned lambs on farms is highly variable – the modelled value may be lower than for some farms.

GrassGro does not model staple strength or vegetable matter contamination of wool. Vegetable matter contamination of wool associated with grazing on grassy annual pastures such as barley grass can lead to large discounts in wool price. GrassGro assumes sheep are healthy – it does not consider parasites such as worms which can substantially reduce production particularly in some regions in some years. Unless preventative management is used, wool and mortality losses from flystrike can be large in some regions in some years. However, these should not be a major source of lower production in a well-managed flock. The genetic merit of sheep, which determine the fleece weight, micron and lambing rates, also has some impact on the net returns from wool and meat sales.

The Farm Monitor Report of Tocker and Berrisford (2011)shows that stocking rates remain a key driver of farm profitability. In the north east Victoria, the area closest to Wagga Wagga in south east NSW, average winter stocking rates for prime lamb enterprises was 9 DSE per grazed hectare in 2001/2011 and the year before.

McEachern and Francis (2013) report that some wool producers appear "to be missing the opportunity to make the most out of these really good times in wool where both prices and seasons are going well. The opportunity missed appears to have arisen because stocking rates are not matched to potential feed on offer. This is reflected in very good profits per DSE but only average profits per hectare per 100 millimeters of rainfall. Some individual producers will have sound reasons for not being able to better match stocking rate to rainfall because the land classes managed cannot make use of the additional rainfall. Others have missed a very lucrative opportunity."

7.4 Prices

The price series used in the MIDAS analyses are in Table 7.3 and prices used in the IMAGINE analyses are in Tables 7.4 and 7.5.

The prices used in IMAGINE were different to those for MIDAS because they account for expected prices of the next 40 years. For the sake of parsimony and simplicity we assumed the same prices for historical and future scenarios in MIDAS. Fortuitously the long range past and forecast prices are not different enough to warrant additional scenario analysis in this respect (OECD-FAO 2012). Analysis of alternative price projections presents a considerable level of complexity and sophistication, and is a gap best filled with future research as it is beyond the scope of this project.

Regional prices are likely to differ in various categories depending on local and export market conditions. Once again this was beyond the scope of the analysis as the important issue here was to evaluate the economic impact of changes in yields and productivity due to climate change. So the prices and costs were handled as simply as possible in order to enable us to observe the farm economic implications of climate change and choice of perennials as an adaptation mechanism.

The prices used in MIDAS are expected 10-year averages, whereas the IMAGINE analyses are for prices spanning 40 years. The MIDAS prices are slightly higher because they reflect the current as well as near-term market conditions (see OECD-FAO (2012)).

Table 7.3 Prices used in MIDAS analyses

Item	Unit	Price
Cunderdin and Katanning		
Wool	c/kg clean fleece weight[a]	800
Shippers (2 year-old wethers)	$/head[a]	60
Meat price	$/kg[a,b] dressed weight of Merino prime lamb	4
CFA ewes	$/head[a]	50
Wheat	ASW $/tonne [c]	259
Barley	Malting $/tonne [c]	293
Canola	$/tonne [c]	527
Field peas	$/tonne [c]	262
Lupin	$/tonne [c]	242
Mallee	$/green tonne [d]	24
Hamilton		
Wool	c/kg clean fleece weight[a]	800
Shippers (2 year-old wethers)	$/head [a, b]	60
Meat price	$/kg[a] dressed weight of Merino prime lamb	
CFA ewes	$/head[a]	50
Mallee	$/green tonne [d]	24

[a] Farm gate prices
[b] 21kg dressed weight (45 kg live weight), no skin value
[c] Grain prices are farm gate for the decade prior to 2012 and the decade that follows it. FOB prices are generally about $55 per tonne higher than farm gate
[d] $/green tonne stumpage (farm gate) includes planting, fertiliser, land rent (opportunity cost) and competition, but does not include harvest and haulage and road transport

Table 7.4 Prices and costs of sheep enterprises used in IMAGINE

Sheep class	Wool	Wool cut	Sheep sales	Sheep sales	Husbandry costs
	$/kg	kg/head	$/head CS2	$/head CS3	$/head/month
Ewes	7.50	6.50	8 (CFA)	50 (CFA)	0.2
Ewe hoggets	8.50	6.40	64	66	0.2
Ewe lambs	3.70	4.74	47	50	0.2
Wethers	7.50	6.10	54	58 (CFA)	0.2
Wether hoggets	8.50	6.65	50	53	0.2
Wether lambs	3.70	4.80	51	54	0.2

CFA means Culled for Age, CS2and CS3 refer to condition score of sheep at sale. Wool cut and price is for clean fleece.

Table 7.5 Farm gate prices of grains used in IMAGINE

Grain commodity	$/tonne
Wheat	210
Barley	180
Canola	475
Field Pea	215

7.5 Crop yields

The MIDAS whole-farm models and IMAGINE paddock-level models account for mixtures of typical soils at each location. The soil types and areas are important farm-level constraints, which can be represented in farming systems models. With MIDAS, land management units (LMUs) have been specified according to typical soil, vegetation and topographical features for the representative farm at each project location. The LMUs for each version of MIDAS are described in Tables 7.1 and 7.2.

Crop yields used in the MIDAS analyses are in Tables 7.6, 7.7 and 7.8. These yields have been developed based on historical and current yield information and yield projections from plant prediction models for a 2030 dry climate model. The climate downscaling and associated validation for the key climate variables at each project location (maximum and minimum temperatures and rainfall) are described in Chapter 5, and the plant predictions using those climate data are discussed in Chapter 6.

The crop and biomass yields used for the MIDAS analysis at Cunderdin were generally lower in the future than for the historical case. However, the yield reductions were not large. And there are some cases (for barley and field pea on some LMUs) where the predicted yields are slightly higher in the future compared to the past.

At Katanning the crop and mallee biomass yields were nearly always lower in the future than for the historical case however, these reductions were generally not very great. However, pasture biomass yields were greater (see Chapter 6).

At Hamilton the current land use does not include cropping, and so the MIDAS model only contains pasture and mallee biomass activities. The mallee yields are predicted to be slightly higher in the future on LMUs 2 and 3 at Hamilton.

The report of Tocker and Berrisford (2011), as well as our interviews with Hamilton growers, indicate that some growers do grow grain crops comprising of cereal and broad leaf break crops such as canola. Although we did not have the resources to modify the Hamilton MIDAS model and validate it for grain crops for this project, we were able to use IMAGINE to assess the profitability and cash flow of a typical grain crop rotation at Hamilton.

Table 7.6 Crop yields in MIDAS: Cunderdin

	Crop yield (t/ha)					
LMU	Wheat	Barley	Canola	Field Pea	Lupin	Mallee
Historic climate						
1	0.86	n.a.	n.a.	n.a.	0.40	9.7
2	1.63	1.35	0.76	n.a.	1.33	9.7
3	2.30	1.94	1.14	n.a.	1.44	10.7
4	1.98	1.81	0.94	1.2	0.79	8.2
5	1.95	2.00	1.02	1.2	0.99	11.2
6	2.17	2.13	1.00	1.4	n.a.	9.7
7	1.97	1.93	0.90	1.0	n.a.	9.7
8	2.04	1.97	1.00	0.8	1.26	11.2
2030 dry climate						
1	0.79	n.a.	n.a.	n.a.	0.38	8.1
2	1.47	1.38	0.74	n.a.	1.26	7.8
3	2.08	1.90	1.11	n.a.	1.36	9
4	1.71	1.78	0.88	1.20	0.75	6.7
5	1.75	1.96	1.00	1.23	0.93	9.3
6	1.97	2.09	0.97	1.44	n.a.	8.1
7	1.77	1.90	0.88	1.04	n.a.	8.1
8	1.85	1.94	0.97	0.84	1.19	9.4

n.a. Not applicable

Table 7.7 Crop yields in MIDAS: Katanning

	Crop yield (t/ha)					
LMU	Wheat	Barley	Canola	Field Pea	Lupin	Mallee
Historic climate						
1	0.11	0.19	n.a.	n.a.	n.a.	14.5
2	0.85	1.05	n.a.	0.06	0.15	14.5
3	1.41	1.58	n.a.	0.42	0.80	16
4	2.13	2.77	0.63	1.45	1.28	12.3
5	2.22	2.40	0.63	1.45	1.28	16.7
2030 dry climate						
1	0.10	0.18	n.a.	n.a.	n.a.	14.1
2	0.78	1.02	n.a.	0.04	0.12	13.9
3	1.30	1.90	n.a.	0.38	0.71	15.3
4	1.96	2.22	0.59	1.34	1.14	12.2
5	2.04	2.31	0.59	1.34	1.14	16.5

n.a. Not applicable

Table 7.8 Mallee yields in MIDAS: Hamilton

	Mallee yield (t/ha)	
LMU	***Historic climate***	***2030 dry climate***
1	18.9	18.9
2	18.9	19.4
3	20.7	21.4

7.5.1 Mallee yields

A summary of whole-farm mallee yields by location at each harvest (coppice) over 40 years is in Table 7.9. As expected, yields vary with location due to soil and rainfall characteristics as discussed in Mendham et al. (2012) and Peck et al. (2012). Biomass yields are greater in the eastern state locations than in the west.

The biomass of mallee consists of both above and below-ground components. Simulated mallee growth for each on loamy deep sands at Katanning is in Figure 7.1.

Table 7.9 Whole-tree biomass yield of mallees expressed in green tonnes per hectare per harvest: future climate scenario: all locations

Harvest Year	Katanning gt/ha	Cunderdin gt/ha	Hamilton gt/ha	Wagga gt/ha
6	59	38	79	79
10	67	41	74	74
14	65	36	75	75
18	69	42	77	77
22	72	41	77	77
26	69	38	78	78
30	67	38	80	80
34	68	40	79	79
38	72	42	78	78
Total	606	356	696	696
Average	67	40	77	77
Stdev	1.4	2.4	3.4	4.4
cv	2%	6%	4%	6%

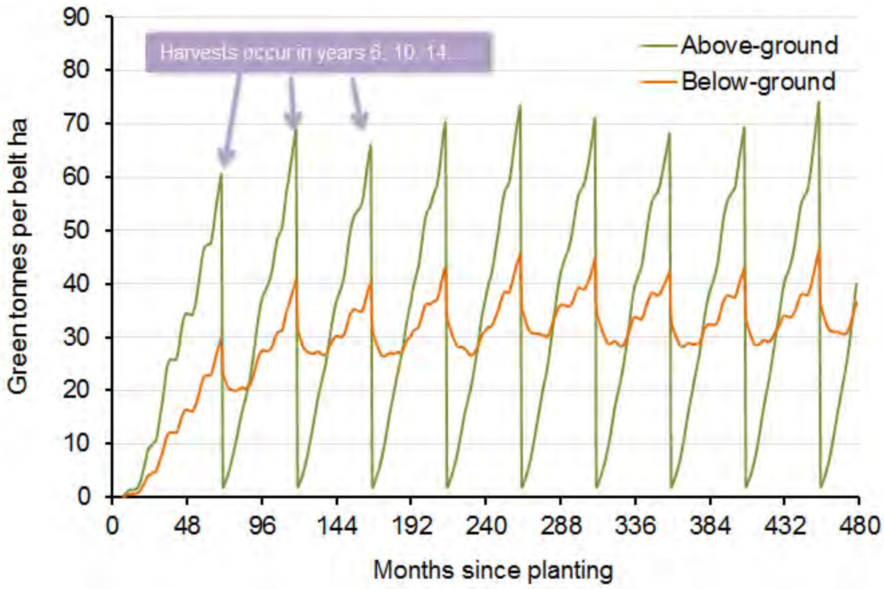


Figure 7.1 Simulated mallee growth above and below ground in 2-row belts of trees harvested periodically: example from Katanning on loamy deep sands: future climate scenario

7.6 Detailed system comparisons

For pastures used in livestock production, the major comparison was of annual versus perennial pastures. Perennial pastures, due to deeper rooting depth, are considered to be more suitable in adapting to a changed (warmer and drier) climate. However, in regions such as Hamilton perennials are the counterfactual, being a part of the existing land use systems. In this case, new perennials were tested, and in others the performance of existing perennial pastures was tested in a new climate. One new perennial plant species (Tedera (*Bituminaria bituminosa*) was analysed at Cunderdin and Katanning by Finlayson et al. (2012a).

It should be noted that the projected climate contains changes in temperature and rainfall at specific times which can also affect the performance of existing species (e.g. winters in southern Victoria may provide conditions that are less cold and water logged for pastures). Changes in CO_2 levels were also included in the plant predictions (Chapter 6).

For crops, the effects of predicted changes in yields of existing crop species were tested in the whole-farm and paddock-level models for both historic and a projected future climate. For pastures, the changes in seasonal plant biomass were also included in these comparisons (Chapter 6).

A new farm enterprise (mallees for biomass production planted in alleys in either pasture or crop paddocks) was also tested with analytical techniques reported in Abadi et al. (2013) and Mendham et al. (2012). This farm enterprise is hypothetical in a sense because a mallee biomass industry is a prospective one at this stage (Bartle and Abadi (2010)). The analysis of this whole-tree coppice biomass production will require further development of a market for biofuels and bioenergy and establishment of local processing plants ranging from combined heat and power systems (CHP) to pyrolysis plants for production of Bio-crude oil and manufacture of transport fuels. Substantial research has been conducted for mallee for biofuels and there is significant interest in the development of such an industry as reported in a major report by Bioenergy Australia published in Stucley et al. (2012)

The detailed farming system comparisons are in Table 7.10. The choice of farm enterprise within each MIDAS analysis to achieve the profit objective was not constrained by the initial enterprise chosen on any particular LMU. That is, in the whole-farm analysis the best farm activity on any LMU could change as the scenario was varied (i.e. as perenniality or mallee biomass activities were added for either climate scenario).

Table 7.10 Detailed farming systems comparisons at the four project locations [a]

Location	Enterprise	Base case (B)	Base plus perennial pastures (PP)	Base plus perennials plus mallee (M)
Cunderdin	Pasture	Annual pasture (AP)	AP + lucerne + tedera	B + PP + M
	Crop	Crop rotation	Crop rotation	Crop including M
Katanning	Pasture	Annual pasture (AP)	AP + lucerne + tedera	B + PP + M
	Crop	Crop rotation	Crop rotation	Crop including M
Wagga	Pasture	AP + lucerne	AP + lucerne + fescue + phalaris	AP + lucerne + fescue + phalaris + M
	Crop	Crop rotation	Crop rotation	Crop including M
Hamilton	Pasture	Continuous PP (Kikuyu, perennial ryegrass and sub-clover)	Continuous PP + Fescue + lucerne + sub-clover	Continuous PP + Fescue + lucerne + sub-clover + M

[a] All comparisons for historic and future climates. AP is annual pasture comprising a mixed sward of annual ryegrass, sub-clover pasture as well as some weeds. PP is the perennial pasture of sward of existing or new perennial pastures such as kikuyu, perennial ryegrass, lucerne, fescue and phalaris. M is mallee trees grown in belts for their biomass.

8. Discussion and future directions

8.1 Introduction

In this research project a whole-farm economic analysis of mallees for biomass has been conducted. Although this potential industry has been investigated (e.g. see Stucley et al.(2012)) its development depends on establishing a market and value chain for biomass. In this chapter we comment on this issue.

Also from the research reported here there are a number of points that can be made about issues for policy and further research. We present discussion of the main points from our deliberations.

8.2 Mallee biomass value chain and drivers of viability

Over the last 20 years, a strong partnership has conducted research that was sharply focused on developing the supply chain from tree planting to biomass delivery at the processor's door. The contributors to this partnership have been Department of Environment and Conservation, FFI CRC, CSIRO, Biosystem Engineering Pty Ltd, University of Curtin, University of Western Australia, Department of Agriculture and Food Western Australian, and several others.

The aim was to develop mallees as a biomass tree crop that can be cohesively integrated into existing farming systems with minimal interruption to normal operations of livestock and cropping enterprises. A woody biomass crop must be profitable and diversify revenue risk by enabling farmers to supply biomass and sequester carbon to relevant markets. The objective was to design a mallee belt planting layout that minimizes costs (such as competition on nearby agricultural crops and pastures) and maximizes benefits when planted in appropriate agro-climatic zones and edaphic conditions.

Biomass, a bulk commodity produced by clusters of farmers, can be harvested by one or more firms that have the specialized equipment and haulage logistics handling and transport systems to deliver it to firms that will use it for fuel and power in regional towns. Users may be an abattoir, feed mill or a biofuels producer. These biomass users will also be able to utilize straw, grass crops and residues from plantation forestry as their feedstock of biomass. The ability to use a variety of feedstocks, as a biomass complex, provides security of supply to buyers and builds a buffer capacity. For mallee biomass to have a value chain in the bioenergy and biofuels industries its scale of use must be significant enough to warrant capital investment that develops adequate economies of scale so that it is profitable for all the participants in the longer term.

There are currently about 14,000 ha of mallees across about 1,000 farms in the grain-livestock zone of south-western Australia. There have been many initiatives over the years to develop local markets for mallee products, including eucalyptus oil, panel board, activated carbon, electricity generation in stand-alone plants and for co-firing. A great deal has been learnt from these attempts. The current strategy is to facilitate local use for combined heat and power (CHP) in plants such as abattoirs and essential oil distilleries. The FFI CRC is currently conducting work on the mallee-to-jet fuel chain.

Mallees are clearly not the only source of lignocellulosic biomass. Cereal straw and residues from plantation forestry or city/town waste are other potential biomass supply options for bioenergy and biofuels processors. These sources are complementary and biomass buyers are likely to welcome relatively stable year-to-year yields from mallees that offset the more variable straw yield. Forestry residues, where available, are a valuable option in the early phases of the operation of a bioenergy plant, but their supplies are likely to dwindle over the future decades, particularly in the 450-650 mm rainfall parts of southern Australia, as growing block planted forests becomes less viable.

FFI CRC with its collaborators will continue to research where these technological breakthroughs can be achieved, and is currently consulting with potential partners in a new sustainable biomass research alliance to carry this work forward.

The value chain for mallees is in the developmental and proof-of-concept stage. The growing of mallees is well practiced and well understood. A prototype harvester (see Fig 8.1. P1 Mallee Harvester as it is known) has been built and it has recently completed field trials successfully (see below). The owner of the intellectual property for the design of the harvester, Biosystems Engineering Pty Ltd is commercializing the harvester and planning to manufacture a second prototype that will be more efficient with higher biomass flow rate to further reduce harvesting costs. A transport fuel sample is likely to be produced in 2013 from proven fast pyrolysis technology and pre-commercial upgrading technology.

Figure 8.1. P! Mallee Harvester. Source: Permission received courtesy of FFICRC.

Research to date has included breeding elite mallee genotypes with superior biomass and eucalyptus oil yield; assessing different farm layouts for optimum water use and minimal trade-off with adjacent crop and pasture yields; calibrating nutrient use and export, and replacement fertiliser requirements; developing and commercializing the mallee harvester; evaluating different harvesting regimes; conducting supply chain economic analyses and estimating the delivered cost of biomass; modelling landscape-scale water use and potential salinity mitigation; and observing the biodiversity benefits.

FFI CRC has consulted widely, including with the mallee growers' industry representative body and regional non-government organisations, on how to support commercial development of this supply chain. This included use of existing mallee plantings initially, while coordinating new plantings and planning harvesting, haul-out and transport operations for a profitable, regional value chain.

In undertaking its research the FFI CRC and its partners have focused on sustainable production of whole-tree biomass from mallee belt planting in broadacre agricultural systems. Some key research activities in this regard have included the 'delivered cost of biomass' study, comprising a series of economic analyses which have calibrated the value chain using outputs from the Gen2 study and other research in collaboration with Western Australia Department of Environment and Conservation, to segregate costs for each step along the value chain.

The most recent version of this work, led by Amir Abadi, has been published by Bioenergy Australia as part of its updated book on bioenergy in Australia (Stucley et al. (2012)). Wu et al. (2008) presented a systematic analysis of overall energy balance of mallee biomass production in Western Australia showing that it has a strong energy gain with an energy ratio (the ratio of total energy outputs and total non-renewable energy inputs) of 42 and an energy productivity of 206 Giga Joules (GJ) per ha per year. This performance by a perennial woody crop is considerably better than that achievable by annual energy crops. Canola (rapeseed) for biodiesel, in the same region, has energy ratios that are typically less than 7 and energy productivities are less than 40 GJ/ha/year. Yu et al. (2009) investigated mallee biomass as a key bioenergy source in Western Australia looking at the importance of biomass supply chain. The study was based on a continuous, integrated, and streamlined supply chain from farm to the bioenergy plant and evaluations based on the road systems in the same region. It showed that the delivered cost of mallee biomass depends on feedstock collection distance, road transport distance, and proportion of the land planted to mallee. Yu et al (2009) suggested strategies for reducing the delivered cost of mallee biomass including locating the biomass processing plant near areas of high planting density; managing or upgrading on-farm tracks and roads; planning seasonal schedules, or improving haulage efficiency to minimize on-farm haulage cost; and integrating road transport into the business of either biomass growers or biomass processing plant owners, rather than that of independent third parties as transport service providers because separate ownership leads to increased cost.

A study by WorleyParsons Pty Ltd, commissioned by Verve Energy in 2008-2009, compared the economic and social costs and benefits of renewable energy plants, using mallee biomass in the south west of Western Australia. Capital expenditure, operations and maintenance expenditure, electricity sale revenue, renewable energy certificate revenue and capacity payment revenue were examined. The external parameters were also considered and they included regional employment, LandCare benefits, carbon emissions and water use. The benefit of the bioenergy plant to the State was estimated using levelised present value cost per mega watt hour - the basic unit of energy. That study found that, for regional communities, a farm based biomass system was a clear winner (Don Harrison, Verve Energy, as reported in Countryman 22/04/2010).

The Gen2 study was a major analysis of water interception, nutrient replacement, tree and adjacent crop productivity and paddock layout for mallees in the target region funded by the Australian Government's Second Generation Biofuels R&D Program and completed in 2012. The project was collaboration between FFI CRC and Curtin University of Technology with Dr Daniel Mendham, CSIRO, as the Principal Investigator (Mendham et al. (2012)). The 'mallee productivity' study was a companion analysis to the Gen2 study providing data on variability of yields and other inputs and services involved in production, along with the impact of different harvest regimes (Peck et al. (2012)). The Sustainable Mallee Jet Fuel project is focused on sustainability assessment and life cycle assessment (LCA) of an Australian value chain for farm-grown mallee biomass being led by Kevin Goss at the FFI CRC. The LCA assessment component of that study is looking at greenhouse gas emissions, energy demand and fossil fuel depletion. This LCA element is being undertaken by RMIT University, Melbourne. This work was in preparation in May 2013.

Mallees are well adapted to the Australian environment and the potential planted area is large. However, the actual plantings for biomass supply is an economic question, relative to profitability of existing food (grain, meat) and fibre (wool) production, and not a biological one. The growth in planting and production will be determined by market and more practical considerations. Looking at the historical growth and development of analogous tree based industries, such as blue gum forestry (for paper pulp) in Australia, it may be estimated that access to finance, labour and other resources, and the logistics of a start up industry will likely limit mallee growth to about 100,000 hectares per annum. Another example of a new industry based on trees on farms is the current trajectory of mallee plantings for permanent carbon sequestration plantings with 65,000 hectare stands established to date.

Mallee biomass will compete with other sources of bioenergy on its delivered cost to processors, which will be influenced by yields on farm, supply chain costs, proximity to processing plants and security of supply. In this context FFI CRC has recently completed a major supply chain study (Stucley et al. (2012)), which estimated the cost of biomass landed at the processor's gate to be in the range of $53 to $70/green tonne.

The value of concomitant benefits of mallees plantings were also estimated by Amir Abadi and his collaborator as reported in Stucley et al (2012). These benefits included reduced waterlogging of crops in alleys in some seasons, protection of biodiversity and public assets from salinity, revenue from carbon sequestration, and reduced livestock mortality. If these co-benefits are included the delivered cost of mallees biomass is lowered to between $37 and $68 per green tonne. The material realization of these benefits depends on who captures the benefits.

A recent investigation, internally conducted by the FFI CRC, of a mallee supply chain developed around fast pyrolysis plants in or near Katanning investigated conversion of 150,000 dry tonnes a year of mallee biomass into pyrolysis oil (for conversion to transport fuel) and biochar. The processing plant is assumed to have a work rate of 200 dry tonnes dry tonnes per day and to be able to function most of the year. For this biofuels enterprise harvesting would need to be rostered across clusters of farms, each sharing a landing site for resource aggregation. Each biomass producing cluster is estimated at about 10 km radius comprised of 13 farms (31,200 ha total area). With mallee planting on pasture land taking up about 6% of the paddocks mallees will be grown on 3% of the participating farms. Assuming that 50% of farmers chose to adopt the new mallee system, each cluster can generate 5,500 dry tonnes of biomass per year from 1.5% of the cluster area. To meet the processor annual demand for biomass will require 27 clusters and 351 participating mallee growers planting around 15,000 belt hectares of trees across a land area of close to 850,000 ha.

From this perspective farm production of sustainable bioenergy and biofuels in the next one or two decades is a significant but achievable, potential enterprise for the agricultural sector that could deliver economic, social and environmental benefits as shown in this report. However, it will not yet be so large enough to displace food (e.g. wheat, canola, sheep meat) and other fibre (e.g. wool) production, which are the major commodities of Australian dryland agriculture. Evidence of the likely degree of direct and indirect land use change attributable to mallees as a biofuel source requires further analysis.

8.3 Directions for future R&D and policy

Conducting this research has brought to light several areas of future R&D and policy priority.

8.3.1 Yield gap research

There exists a significant yield gap between potential yield as demonstrated by research results and simulations and average farm-level crop yields. There is a need for further applied research to increase on-farm yields towards the biophysical limit. This is the issue of what is achievable on farms versus what is possible when production constraints are not limiting, that is, the yield gap reported on by Davidson and Martin (1965). This issue has also been recently discussed in depth by van Ittersum et al. (2012) and Hochman et al. (2012), and the bridging of this gap could offer substantial advantages to Australian agriculture in future (Stirzaker 2012).

The value and success of decision support tools in agriculture (McCowan (2002), Meinke et al. (2001)) is also relevant in promoting change through improved decision making, but these authors noted substantial problems with the successful use of such tools.

In our analyses we used models of climate, plant physiology and farming systems to predict plant and livestock responses in a changed climate and assessed their likely impacts on the economics of farming. Our project is a clear demonstration of the important role of modeling. Mathematical modelling is the only way to predict plant responses in these situations (Moore (2012), Oliver et al. (2009)). Agricultural adaptation responses will vary by region (Malcolm *et al.* 2012). The model we used for grain crop yields was APSIM and for pastures and livestock we used GrassGro. These models simulate plant growth, grain yields and livestock production. To simulate mallee growth and biomass crop yields we used IMAGINE in conjunction with field trial data reported in Peck et al (2011) and Mendham et al (2012).

For economic evaluation of systems with and without perennial innovations we used MIDAS and well as IMAGINE. These enabled us to evaluate the economic impact of perennials in a farming systems context. These economic models are complementary. Physiological models that simulate growth and yield need to be used in conjunction with farming systems economics models that provide the ability to assess the economic impacts of innovations in a whole-farm context and indicate their likely cash flow consequences.

To calibrate our whole-farm and paddock-level models we needed to adapt the model inputs to account for this yield gap issue. We looked at sources of farm-level (crop) productivity (McEachern and Francis (2013), Tocker and Berrisford (2011), Planfarm BankWest (2012)), generally for the last 10 years, and compared these crop yields with APSIM yield predictions for the same years and locations. While the correlations were not large, the average yield gap between simulated yields and farm yields was about 50%. Therefore we reduced the

APSIM yields substantially for the farm-level modelling (i.e. in calibrating the models for the conditions experienced by growers).

Hence a major implication for Australian agricultural industry practice is to increase on-farm crop yields to achieve outcomes closer to what may be potentially possible. This is a call for more applied R&D on this issue.

8.3.2 Incorporating yield and price variability

This issue relates to the interaction between price variability and plant yield variability in economic research. There is a distinct possibility that downside risk for farm incomes could be exacerbated by price fluctuations. In our work we were not able to investigate the possible impacts of price variability in association with plant yield variability under a changed climate due to constraints of project resources, particularly time. Such analyses are important and should be a future research priority.

8.3.3 Assessing drought options

Our paddock-level analyses of pastures and livestock enterprises showed that in low rainfall years the need for supplementary feeding could increase substantially, increasing the costs and accentuating the losses in those years. If whole shires or regions are affected by drought then large-scale options to either sell or agist livestock could be required. An analysis of the regional opportunities and impacts in these scenarios will be valuable.

8.3.4 Regional impacts of climate change

Associated with the above point, our analyses showed that impacts are likely to vary by region.
There is a need for regional-level work to consider options for support for livestock industries when state or regional level drought feeding or agistment are required.

8.3.5 The place of mallees

Mallees appear to offer a reasonable niche for dryland agricultural areas. The mallee enterprise is only recommended in planting layouts that occupy 5-10% of farm land (if the alley system as proposed is implemented). Mallees are unlikely to be as affected by drought as other agricultural plants. But if a reasonable price is offered ($24/gt was used in this analysis, and this is competitive with biomass from other agricultural sources – straw and hay) then mallees can have a valuable role in reducing adverse impacts of droughts. Some R&D has been undertaken on industry development (supply chain) aspects of a developing mallee biomass industry (Stucley et al. (2012), Enecon (2001) Wu et al. (2008), Yu et al. (2009), EMPA (2012), Mendham et al. (2012), Tonini and Astrup (2012), and Abadi et al. (2013)), but further work is required.

8.3.6 Funding for maintenance and upgrades of farming systems economics models

Institutionally, CSIRO and some affiliated private and public entities have, over the last three decades, put a great deal of effort in resourcing the maintenance, validation and continuous improvement of APSIM and GrassGro so that they are relevant to contemporary issues facing agricultural industries, when used by skilled and experienced personnel. The same level of intellectual attention and resourcing need to be dedicated to farming systems economics models (IMAGINE and MIDAS) so that there are relevant versions with structures and data sets that realistically and accurately represent key broadacre farming systems in Australia. Their continuous improvement and upkeep must also be sustained on an ongoing basis for these bioeconomic models to remain relevant to contemporary issues and challenging facing agriculture.

Appendix A: Economic model information and results

1. Land Management Units

Table A.1 Land Management Unit (LMU) descriptions in MIDAS

LMU	Area (ha)	Name	Description
Cunderdin			
1	140	Poor sands	Loose, white and pale yellow sands. Low moisture and nutrient availability.
2	210	Average sand-plain	Yellow sandy. Cereal yields are limited by moisture and nutrient availability.
3	350	Good sand-plain	Produces high to very high cereal, lupin and pasture yields in most years.
4	210	Shallow duplex soil	Hard setting, heavier, grey to brownish soils. Good moisture and nutrient availability.
5	200	Medium heavy	Above average quality soil suitable for cereals, lupins and pasture.
6	200	Heavy valley floors	Produces good cereals, field pea crops and medic based pastures.
7	300	Sandy surfaced valleys	Suitable for cereal and pasture.
8	390	Deep duplex soil	Generally a productive soil with good moisture and nutrient availability.
Total	2000		
Katanning			
1	100	Saline soils	Shallow saline soils over heavy gleyed or mottled clay.
2	150	Water logged soils	Deep sands often waterlogged over grey gleyed clay.
3	50	Deep sands	Deep sands but not waterlogged over mottled clay.
4	500	Sandy gravels	Gravels and sandy gravels to 500 mm over clay or gravelly clay.
5	200	Sandy loams	Sandy loam, loamy sand over clay. Rock outcropping in landscape.
Total	1000		
Hamilton			
1	200	Low lying	Clay soils in lower slopes that are often waterlogged
2	600	Slopes	Moderately drained loams in the mid slopes
3	200	Crests	Well drained gravelly soils at tops of hills
Total	1000		

Table A.2 LMUs in IMAGINE: Wagga Wagga

LMU	Area (ha)	Name	Description
1	200	Red Chromosol	Red Chromosol (Petroferric)
2	600	Grey Vertosol	Grey Vertosol
3	200	Red Kandosol	Red Kandosol
Total	1000		

2. MIDAS Results for Cunderdin

Table A.3 MIDAS whole-farm results: profit and land use: Cunderdin

	Percentage of farm area (%)					Farm Profit
	Crop	Annual pasture	Perennial pasture		Mallee	
			Lucerne	Tedera		$/ha
Historical climate						
Base	83	17	-	-	-	110
With PP	50	24	4	21	-	129
With PP & Mallee	49	28	4	17	1	131
Future climate						
Base (no PP)	83	17	-	-	-	89
With PP	49	18	27	6	-	113
With PP & Mallee	46	18	28	7	2	116

Table A.4 MVPs (profit contributions) of land use on LMUs: base: historic climate: Cunderdin

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected (area allocated)
1	140	43	Continuous pasture
2	210	120	Wheat, canola, wheat, lupin
3	350	268	Wheat, canola, wheat, lupin
4	210	171	Canola, wheat, barley, lupin (dry sown)
5	200	250	Continuous pasture
6	200	230	Wheat, canola, barley, chickpea
7	300	147	Wheat, canola, barley, field pea
8	390	224	Wheat, canola, wheat, lupin

Table A.5 MVPs (profit contributions) of land use on LMUs: with perennial pastures: historic climate: Cunderdin

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected (area allocated)
1	140	47	Tedera
2	210	138	Continuous pasture, wheat, barley, lupin
3	350	288	Wheat, canola, wheat, lupin
4	210	185	Canola, wheat, barley, lupin (dry sown)
5	200	267	Continuous pasture
6	200	247	3 yr pasture, 1 yr wheat; 2 yr wheat, 1 yr barley, 1 yr chick pea
7	300	179	3 yr lucerne, wheat, barley; 3 yr pasture, 1 year wheat
8	390	247	Tedera, wheat, canola, wheat, lupin

Table A.6 MVPs (profit contributions) of land use on LMUs: with perennial pastures & mallee: historic climate: Cunderdin

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected (area allocated)
1	140	58	Continuous pasture and mallee
2	210	142	Continuous pasture and mallee, wheat, barley, lupin
3	350	293	Wheat, canola, wheat, lupin
4	210	188	Canola, wheat, barley, lupin (dry sown)
5	200	262	Continuous pasture and mallee
6	200	248	2 yr wheat, 1 yr barley, 1 yr chick pea
7	300	174	3 yr lucerne, wheat, barley, 3 yr pasture, 1 yr wheat
8	390	252	Tedera, wheat, canola, wheat, lupin

Table A.7 MVPs (profit contributions) of land use on LMUs: base: future climate: Cunderdin

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected (area allocated)
1	140	25	Continuous pasture
2	210	102	Wheat, canola, barley, lupin
3	350	235	Wheat, canola, wheat, lupin
4	210	160	Wheat, canola, barley, field pea
5	200	236	Continuous pasture
6	200	222	Wheat, canola, barley, field pea, wheat, canola, barley, chick pea
7	300	134	Wheat, canola, barley, field pea
8	390	192	Wheat, canola, wheat, lupin

Table A.8 MVPs (profit contributions) of land use on LMUs: with perennial pastures: future climate: Cunderdin

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected (area allocated)
1	140	43	Continuous pasture
2	210	125	Continuous pasture
3	350	252	Wheat, canola, wheat, lupin
4	210	181	3 yr lucerne, wheat, barley, 3 yr lucerne, wheat, barley
5	200	245	3 yr lucerne, wheat, barley, continuous pasture
6	200	231	Wheat, canola, barley, field pea
7	300	173	3 yr lucerne, wheat, barley
8	390	225	3 yr lucerne, wheat, barley, 4 yr lucerne, wheat, canola, barley, lupin, wheat, tedera

Table A.9 MVPs (profit contributions) of land use on LMUs: with perennial pastures & mallee: future climate: Cunderdin

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected (area allocated)
1	140	57	Continuous pasture and mallee
2	210	134	Continuous pasture and mallee
3	350	257	Wheat, canola, wheat, lupin
4	210	182	3 yr lucerne, wheat, barley
5	200	246	3 yr lucerne, wheat, barley, continuous pasture
6	200	237	Wheat, canola, barley, field pea
7	300	175	3 yr lucerne, wheat, barley
8	390	229	4 yr lucerne, wheat, canola, barley, lupin, wheat, 4 yr lucerne, wheat and mallee, tedera

3. MIDAS Results for Katanning

Table A.10 MIDAS whole-farm results: profit and land use: Katanning

	Percentage of farm area (%)					Farm Profit
	Crop	Annual pasture	Perennial pasture		Mallee	
			Lucerne	Tedera		$/ha
Historical climate						
Base	34	66	-	-	-	183
With PP	25	44	13	17	-	234
With PP & Mallee	25	33	13	26	3	237
Future climate						
Base (no PP)	25	75	-	-	-	205
With PP	13	35	36	16	-	274
With PP & Mallee	13	25	35	25	2	276

Table A.11 MVPs (profit contributions) of land use on LMUs: base: historic climate: Katanning

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	100	16	Continuous pasture
2	150	112	Continuous pasture
3	50	150	Continuous cereal
4	500	285	5 yr pasture, 3 yr cereal, continuous cereal, 1 yr pasture, 1 yr cereal
5	200	315	5 yr pasture, 3 yr cereal, 1 yr pasture, 1 yr cereal

Table A.12 MVPs (profit contributions) of land use on LMUs: with perennial pastures: historic climate: Katanning

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	100	119	Tedera
2	150	160	Continuous pasture
3	50	281	Tedera
4	500	327	3 yr lucerne, 5 yr crop (wheat, canola, wheat, lupin, wheat), 5 yr pasture, 2 yr cereal
5	200	364	5 yr pasture, 2 yr cereal, tedera

Table A.13 MVPs (profit contributions) of land use on LMUs: with perennial pastures & mallee: historic climate: Katanning

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	100	131	Tedera and mallee
2	150	172	Continuous pasture and mallee
3	50	278	Tedera with mallee
4	500	326	3 yr lucerne, 5 yr crop (wheat, canola, wheat, lupin, wheat), 5 yr pasture, 2 yr cereal
5	200	364	5 yr pasture, 2 yr cereal, tedera

Table A.14 MVPs (profit contributions) of land use on LMUs: base: future climate: Katanning

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	100	21	Continuous pasture
2	150	85	Continuous pasture
3	50	162	Continuous pasture
4	500	276	5 yr pasture, 3 yr cereal, 1 yr pasture, 1 yr cereal
5	200	274	5 yr pasture, 3 yr cereal, 1 yr pasture, 1 yr cereal

Table A.15 MVPs (profit contributions) of land use on LMUs: with perennial pastures: future climate: Katanning

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	100	138	Tedera
2	150	211	Continuous pasture
3	50	318	Tedera
4	500	370	4 yr lucerne, 1 yr wheat, 5 yr pasture, 2 yr cereal
5	200	410	4 yr lucerne, 1 yr wheat, 5 yr pasture, 2 yr cereal, tedera

Table A.16 MVPs (profit contributions) of land use on LMUs: with perennial pastures & mallee: future climate: Katanning

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	100	146	Tedera and mallee
2	150	218	Continuous pasture and mallee
3	50	318	Tedera
4	500	368	4 yr lucerne, 1 yr wheat, 5 yr pasture, 2 yr cereal
5	200	410	4 yr lucerne, 1 yr wheat, 5 yr pasture, 2 yr cereal, tedera

4. MIDAS Results for Hamilton

Table A.17 MIDAS whole-farm results: profit and land use: Hamilton

	Percentage of farm area (%)			Farm Profit
	Base perennials	Lucerne	Mallee	$/ha
Historical climate				
Base (no PP)	100	-	-	300
With PP	80	20	-	345
With PP & Mallee	75	19	6	347
Future climate				
Base (no PP)	100	-	-	255
With PP	80	20	-	308
With PP & Mallee	75	19	6	310

Table A.18 MVPs (profit contributions) of land use on LMUs: base: historic climate: Hamilton

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	200	403	Continuous pasture with kikuyu or perennial ryegrass and sub-clover
2	600	382	Continuous pasture with kikuyu or perennial ryegrass and sub-clover
3	200	357	Continuous pasture with kikuyu or perennial ryegrass and sub-clover

Table A.19 MVPs (profit contributions) of land use on LMUs: with perennial pastures: historic climate: Hamilton

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	200	429	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover
2	600	420	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover
3	200	479	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover

Table A.20 MVPs (profit contributions) of land use on LMUs: with perennial pastures & mallee: historic climate: Hamilton

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	200	426	Continuous pasture with kikuyu or perennial ryegrass and sub-clover with mallee belts on 6%
2	600	423	Continuous pasture with kikuyu or perennial ryegrass and sub-clover with mallee belts on 6%
3	200	486	Continuous pasture with kikuyu or perennial ryegrass and sub-clover with mallee belts on 6%

Table A.21 MVPs (profit contributions) of land use on LMUs: base: future climate: Hamilton

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	200	434	Continuous pasture with kikuyu or perennial ryegrass and sub-clover
2	600	308	Continuous pasture with kikuyu or perennial ryegrass and sub-clover
3	200	298	Continuous pasture with kikuyu or perennial ryegrass and sub-clover

Table A.22 MVPs (profit contributions) of land use on LMUs: with perennial pastures: future climate: Hamilton

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	200	380	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover
2	600	361	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover
3	200	515	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover

Table A.23 MVPs (profit contributions) of land use on LMUs: with perennial pastures & mallee: future climate: Hamilton

LMU/Soil	Area (ha)	Profit contribution ($/ha)	Rotations selected and (area allocated)
1	200	379	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover with mallee belts on 6%
2	600	366	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover with mallee belts on 6%
3	200	503	Continuous pasture of fescue in combination with kikuyu or perennial ryegrass and sub-clover with mallee belts on 6%

Appendix B: Climate data

Climate data for key variables by month and location

Table B.1 Mean minimum daily temperature: SILO and 18 GCM projections: by month: Cunderdin

^{o}C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	17.1	17.5	15.8	12.8	9.3	7	6	5.9	6.9	9.2	12.6	15.2
BC 2012-2052	17.8	18.4	17	13.6	10.8	8.2	6.9	7	8.3	10.1	13.8	16.6
CM 2012-2052	18.5	18.8	16.6	13.2	10	7.7	6.6	6.9	7.9	9.9	14	17.5
CN 2012-2052	17.5	18.2	16.9	14.5	10.2	7.6	6.5	6.5	7.7	9.6	13.1	16.1
S1 2012-2052	17.8	18.3	16.7	13.8	10.2	7.8	7	6.8	7.6	9.8	13.8	17
S2 2012-2052	18.8	19.4	16.8	13.8	11	8.4	7.2	7.2	8	9.9	13.7	17.5
EC 2012-2052	17.7	17.5	16.5	13.5	9.8	7.3	5.8	6.6	7.3	9.8	13.5	15.8
EG 2012-2052	17.7	18	16	13.3	10.7	7.8	6.7	6.8	7.6	10.4	13.4	16
G1 2012-2052	17.5	18	16.5	13.4	10.3	7.5	6.6	6.7	7.7	10.1	13.2	15.9
G2 2012-2052	17.8	18.3	16.4	13.4	10.1	7.6	6.6	7	7.9	10.3	13.8	16.5
GH 2012-2052	17.7	18.1	16.4	13.8	10.6	8	6.4	6.5	7.9	9.7	13.4	16.7
HA 2012-2052	18.3	18.5	16.5	13.6	9.8	7.7	6.8	6.8	7.4	9.9	13.2	16.2
HG 2012-2052	18	17.6	16.6	13.4	10.8	8.1	7.2	6.6	7.3	9.8	12.8	16.3
IN 2012-2052	17.7	17.7	16.5	13.8	10.2	7.9	6.3	6	7.4	10.2	13.1	15.9
IP 2012-2052	17.9	18.8	17.1	14.2	10.6	7.8	7.1	7.1	7.6	10.1	13.7	16.9
MM 2012-2052	18.8	19.5	17	14.4	10.6	8.7	7.5	7	8.3	10.8	14.6	17.3
MR 2012-2052	17.8	18	16.2	13.3	10.5	8	7.1	7	7.3	9.1	12.8	15.6
NC 2012-2052	17.9	18.4	17.4	14.5	10.3	7.5	6.4	7.4	8	10	13.9	16.6
NP 2012-2052	15.9	15.7	14.3	11.6	8	5.8	4.4	4.6	6.1	7.8	11.4	13.8

Table B.2 Mean maximum daily temperature: SILO and 18 GCM projections: by month: Cunderdin

^{o}C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	34.3	33.6	30.6	26.1	21.4	18	16.8	17.7	20.5	24.7	28.8	32.3
BC 2012-2052	34.8	34	31.2	26.7	22.7	18.8	18.3	18.6	21.6	25.4	30.6	33.1
CM 2012-2052	35.5	34.3	31	26.9	22.2	18.5	17.4	18.8	21.4	25.2	29.8	34.3
CN 2012-2052	34.9	34.1	31.6	27.1	22.3	19.2	17.5	18.9	21	25.7	29.9	33.4
S1 2012-2052	34.9	34.4	31.3	27.2	22.3	19.1	18.1	18.8	21.3	25.6	29.7	33.3
S2 2012-2052	35.6	35.1	31.1	26.7	23.4	19.1	18.3	18.8	21.4	25.3	30	34.5
EC 2012-2052	34.8	33.4	31.1	26.7	21.3	18	17.1	18.3	20.9	25.1	30.7	33
EG 2012-2052	35.3	33.9	30.4	27.1	22.5	18.8	17.6	18.1	21.1	26	29.6	33.3
G1 2012-2052	35.4	34	31.3	27.1	22.3	18.8	17.8	18.5	21.4	25.7	30	32.9
G2 2012-2052	35.1	34.3	31.2	26.5	22.2	18.6	17.8	18.9	21.4	25.8	29.6	33.7
GH 2012-2052	34.7	33.8	31.7	27	21.8	18.3	17.6	18.6	21	25.3	29.7	33.4
HA 2012-2052	35.4	34.6	31.5	26.6	21.5	18.7	17.8	18.4	21.1	25.4	29.6	32.9
HG 2012-2052	34.9	34.1	31.4	26.7	22.2	19.1	17.6	17.9	21.1	25.2	29.4	33.2
IN 2012-2052	35.6	34	31.9	27.6	22.2	18.9	18.3	18.8	21.9	25.9	30	34.1
IP 2012-2052	35.7	35.5	32.1	27.6	22.4	19.1	17.9	18.5	21.6	25.6	31.2	34.2
MM 2012-2052	35.4	35	31.4	27.2	22.9	19.7	18.2	18.6	21.9	26.2	30.4	34.7
MR 2012-2052	34.8	34.5	31.3	26.6	22	18.9	18	18.1	21	25.4	29.3	32.6
NC 2012-2052	35.3	34.1	31.8	27.1	21.9	17.9	17.2	18.9	21.9	25.4	30.6	33.1
NP 2012-2052	35.9	35.9	32.7	27.8	23.9	19.6	18.2	19.1	21.9	26.5	31.6	35

Table B.3 Mean rainfall: SILO and 18 GCM projections: by month: Cunderdin

mm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	16.3	15.1	19.4	24.1	43.2	54.3	57.6	46.9	30.4	16.8	14.9	10.7
BC 2012-2052	16.7	16.4	22.3	24.2	44.4	54.9	45.7	45.3	30.9	21.4	12.4	17
CM 2012-2052	17.2	26.9	24.1	19.9	41.7	48.9	54.5	42.1	24.4	17.4	11.2	11.2
CN 2012-2052	16.5	13.2	16.5	25.8	45.1	47.3	51.2	39.3	30.9	11.6	14.1	13.4
S1 2012-2052	14.3	11.2	15.4	21.2	43.6	52.8	59.6	38.5	28.5	14.4	15.8	8.3
S2 2012-2052	8.2	12.4	31.3	27.2	37.8	59.7	50.7	53	33.8	16.7	9.4	5.4
EC 2012-2052	18.1	16.3	28.9	23.9	59.5	49.6	38.2	49	31.6	18.6	6.1	11.6
EG 2012-2052	25.5	30.3	22	18	48.9	47.4	43.2	48.2	25.2	14.3	14.8	8.3
G1 2012-2052	15	22.1	12	19.4	49	46.6	43.8	42.8	22.9	10.9	12.7	26.7
G2 2012-2052	6.8	16.5	15.4	28.8	39.7	42.5	39.3	35.6	27.9	15.3	23.1	8.7
GH 2012-2052	24.1	19	15.3	24.9	55.5	58.9	54.4	40	33.2	18.5	11.3	9.7
HA 2012-2052	7.5	13.4	15.1	31.3	59.9	54.1	51	54.1	28.7	15.7	13.4	6.2
HG 2012-2052	10.3	11.1	21.5	27.3	56.9	55.8	70.2	49.9	26.7	16.1	11.2	11.6
IN 2012-2052	19.1	14.9	16.6	31.9	45.5	60.7	47.2	39.8	30	17.1	13.1	10
IP 2012-2052	6.8	47.3	16.9	17	36.1	45.2	57.8	49.4	25.2	13.8	7.3	6.6
MM 2012-2052	22.1	20.5	19.9	22.4	42	52.2	54.3	45.4	28.3	13.4	12.8	15.8
MR 2012-2052	13	18.3	23.9	21	54.1	55.1	63.7	53.1	34.1	14.7	13.1	14.6
NC 2012-2052	29.5	20.7	22.3	24.9	49.3	72.3	59.4	44.4	28.1	19.8	17.1	11.1
NP 2012-2052	16.9	18.6	23.2	26.5	46.4	61.1	50.8	50.1	26.2	16.8	16.4	10.9

Table B.4 Mean minimum daily temperature: SILO and 18 GCM projections: by month: Katanning

°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	13.8	14.2	13.0	10.7	8.1	6.2	5.5	5.6	6.4	7.6	10.3	12.3
BC 2012-2052	14.3	15.1	14.1	11.3	9.5	7.7	6.7	6.6	7.5	8.4	11.4	13.5
CM 2012-2052	14.6	14.9	13.9	11.1	8.5	6.6	5.9	6.2	7.0	8.4	11.5	13.5
CN 2012-2052	14.1	14.6	13.7	11.4	8.7	6.8	5.8	6.0	6.8	8.0	10.8	12.8
S1 2012-2052	14.3	14.8	14.0	11.5	9.0	7.2	6.3	6.6	6.8	7.9	11.3	14.0
S2 2012-2052	14.6	15.5	13.9	11.6	9.7	7.5	6.4	6.6	7.1	8.1	11.2	13.9
EC 2012-2052	14.0	14.1	13.2	11.0	8.3	6.5	5.4	6.3	6.3	7.9	10.7	12.9
EG 2012-2052	14.1	14.6	13.7	10.8	8.7	7.0	5.8	5.9	6.8	8.2	10.6	12.6
G1 2012-2052	14.4	14.9	13.3	10.8	8.8	6.7	6.1	6.2	6.8	8.3	11.3	13.1
G2 2012-2052	14.2	14.8	13.6	11.1	8.4	6.9	5.3	6.1	7.1	8.0	11.0	12.9
GH 2012-2052	14.1	14.4	13.2	11.3	8.7	7.0	6.0	6.2	6.9	8.0	10.7	13.3
HA 2012-2052	14.3	14.8	13.9	11.5	8.9	7.0	5.7	6.2	6.7	8.4	11.2	13.1
HG 2012-2052	14.2	14.2	13.9	11.1	8.8	6.7	6.5	5.9	6.5	8.1	10.6	12.8
IN 2012-2052	14.2	14.4	13.8	11.8	9.0	7.3	5.9	5.8	6.7	8.3	10.8	13.0
IP 2012-2052	14.6	15.3	14.0	11.6	8.9	6.8	6.3	6.4	6.8	8.5	11.6	13.5
MM 2012-2052	15.1	16.3	14.5	12.3	9.7	8.5	6.8	6.7	7.6	9.1	12.6	14.2
MR 2012-2052	14.3	14.4	13.6	11.0	9.3	7.3	6.4	6.1	6.5	7.7	10.4	13.1
NC 2012-2052	14.2	15.1	13.9	11.4	8.7	6.7	5.9	6.9	7.5	8.4	11.4	13.3
NP 2012-2052	13.0	12.8	11.7	9.3	7.1	5.3	4.3	4.8	5.7	6.5	9.0	11.0

Table B.5 Mean maximum daily temperature: SILO and 18 GCMs: by month: Katanning

°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	30.1	29.7	27.1	23.1	19.0	15.9	14.9	15.6	17.6	21.0	25.0	28.4
BC 2012-2052	30.9	30.5	28.0	24.0	20.5	16.9	16.1	16.5	19.0	21.9	27.3	30.1
CM 2012-2052	30.8	30.3	27.9	24.1	20.1	16.6	15.5	16.5	18.6	21.2	25.8	30.6
CN 2012-2052	31.0	30.3	28.4	24.5	19.8	16.5	15.5	16.3	18.2	21.9	25.1	29.3
S1 2012-2052	30.7	30.4	27.9	24.4	20.1	16.9	15.8	16.5	18.3	21.7	26.4	29.9
S2 2012-2052	31.3	30.9	27.4	23.8	21.0	16.7	15.8	16.4	18.1	21.3	26.2	30.4
EC 2012-2052	30.4	29.6	27.8	23.9	18.9	16.3	15.4	16.1	17.8	21.4	26.2	29.0
EG 2012-2052	30.8	29.6	27.3	24.0	20.1	16.6	15.6	16.0	18.4	22.1	26.2	28.6
G1 2012-2052	30.9	30.3	27.7	24.0	20.0	16.6	15.8	16.4	18.6	21.8	26.1	29.2
G2 2012-2052	30.6	30.6	27.7	23.2	19.5	16.7	15.3	16.5	18.4	22.0	26.3	28.7
GH 2012-2052	30.7	29.7	27.6	23.6	19.9	16.3	15.4	16.0	18.0	21.4	26.2	30.3
HA 2012-2052	31.3	30.2	28.1	23.6	19.0	16.3	15.5	16.6	18.0	22.2	25.3	29.4
HG 2012-2052	30.5	30.4	27.9	23.5	19.8	16.4	15.5	15.7	18.2	21.1	25.7	29.2
IN 2012-2052	31.4	30.3	28.7	25.2	20.1	16.8	16.1	16.8	18.9	22.0	26.7	30.2
IP 2012-2052	31.3	31.0	28.6	25.0	20.1	16.8	15.5	16.2	18.4	22.0	27.1	30.2
MM 2012-2052	31.6	32.2	28.5	24.9	20.9	17.7	16.0	16.7	19.3	22.8	27.5	31.6
MR 2012-2052	30.8	30.3	27.6	23.5	19.8	16.8	15.7	16.1	18.3	21.1	25.5	30.1
NC 2012-2052	30.6	30.5	28.6	24.4	20.2	16.2	15.3	16.4	19.0	21.8	26.3	29.5
NP 2012-2052	31.8	32.0	29.2	25.3	21.2	17.1	16.1	16.8	18.9	22.4	27.8	31.1

Table B.6 Mean annual rainfall: SILO and 18 GCM projections: by month: Katanning

mm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	19.1	14.5	18.5	30.1	55.9	64.3	71.1	62.2	47.0	30.7	26.7	13.9
BC 2012-2052	21.2	13.5	18.6	28.1	41.2	60.6	66.2	65.0	50.8	35.0	21.4	20.0
CM 2012-2052	11.7	28.4	18.0	22.8	53.1	54.3	66.6	55.7	37.7	30.3	23.9	10.7
CN 2012-2052	20.5	13.1	15.7	30.4	49.9	52.1	63.1	52.3	48.2	22.6	34.8	11.4
S1 2012-2052	9.7	9.3	13.6	34.4	56.0	60.7	72.6	57.4	44.5	25.4	29.1	12.8
S2 2012-2052	10.8	14.2	31.2	43.7	49.5	67.6	64.8	67.0	57.3	28.8	21.4	8.6
EC 2012-2052	27.8	15.5	24.2	27.2	71.0	56.2	52.4	67.0	45.6	32.4	15.5	12.2
EG 2012-2052	25.3	28.4	15.6	21.4	45.4	57.9	55.1	61.6	41.1	21.1	25.4	11.7
G1 2012-2052	17.6	18.6	12.8	22.8	54.2	53.2	57.0	56.3	34.4	21.0	20.1	25.4
G2 2012-2052	7.6	13.1	16.4	36.4	50.5	46.6	51.1	46.1	39.8	27.9	39.2	13.3
GH 2012-2052	27.3	19.2	16.7	36.6	57.8	68.7	69.7	56.7	50.5	35.8	18.7	9.8
HA 2012-2052	10.5	14.0	14.3	35.7	79.4	56.4	55.9	61.0	46.7	27.5	25.8	6.4
HG 2012-2052	18.6	7.5	26.7	32.6	64.3	56.4	76.0	67.9	40.9	29.3	24.1	10.8
IN 2012-2052	19.1	10.3	16.2	40.0	57.7	64.4	61.5	53.4	41.2	30.0	22.4	11.9
IP 2012-2052	9.1	21.9	10.6	14.7	47.3	50.8	70.9	63.1	40.4	26.9	13.8	4.9
MM 2012-2052	35.6	19.2	14.4	26.3	47.4	54.9	60.6	57.6	42.5	23.1	18.1	16.6
MR 2012-2052	15.6	18.5	19.8	28.5	59.4	62.3	77.9	62.2	50.1	29.8	24.9	10.2
NC 2012-2052	26.2	16.4	16.6	28.3	48.8	63.9	73.9	56.0	42.4	32.5	24.7	11.6
NP 2012-2052	17.3	18.3	17.6	32.5	60.6	62.1	68.1	62.7	41.8	29.5	28.9	13.4

Table B.7 Mean minimum daily temperature: SILO and 18 GCM projections: by month: Wagga Wagga

°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	16.7	16.9	14.1	10.1	7.1	4.4	3.4	4.2	5.9	8.3	11.5	14.5
BC 2012-2052	19.3	19.0	15.3	11.7	7.5	4.9	4.2	5.1	7.1	9.0	12.2	16.0
CM 2012-2052	17.7	18.9	15.2	11.3	8.0	5.0	4.8	4.4	6.5	8.5	11.8	15.0
CN 2012-2052	17.9	19.1	16.3	10.5	8.0	4.8	3.4	5.1	6.9	9.0	12.4	15.5
S1 2012-2052	18.0	17.9	15.0	11.2	9.0	5.4	4.8	4.6	7.1	8.7	12.0	15.3
S2 2012-2052	18.0	19.3	16.1	12.1	8.3	5.5	4.0	5.5	6.8	9.4	13.1	16.3
EC 2012-2052	18.3	17.8	15.0	11.3	8.2	4.6	4.1	4.8	6.0	8.9	12.1	16.3
EG 2012-2052	18.4	18.1	15.4	10.4	7.7	5.2	3.5	4.9	6.5	8.6	12.4	15.8
G1 2012-2052	17.1	18.2	15.2	11.5	7.7	5.1	3.9	4.6	6.8	8.8	12.8	15.4
G2 2012-2052	17.2	17.5	15.8	11.8	7.7	5.3	4.1	4.8	7.1	9.3	12.6	14.6
GH 2012-2052	18.4	18.1	15.5	10.6	8.6	5.1	4.2	5.3	6.6	8.6	11.9	15.7
HA 2012-2052	17.6	17.7	15.6	10.6	7.8	4.8	3.7	4.4	6.9	8.8	12.9	15.8
HG 2012-2052	17.8	17.8	14.6	10.8	7.7	5.0	3.7	4.8	6.3	8.6	12.0	15.1
IN 2012-2052	17.6	17.9	14.8	10.8	7.6	4.6	4.4	4.3	5.9	8.6	12.2	15.7
IP 2012-2052	18.8	18.6	16.0	11.7	9.0	5.2	3.9	4.6	6.6	9.3	12.7	16.6
MM 2012-2052	18.9	19.4	14.6	11.1	8.8	5.7	4.7	5.0	7.0	9.2	13.1	15.9
MR 2012-2052	17.8	17.5	14.6	10.8	8.1	5.1	4.3	5.0	6.8	9.0	12.1	15.3
NC 2012-2052	18.7	18.0	15.5	10.8	8.4	5.5	4.3	5.6	7.1	8.8	12.4	15.3
NP 2012-2052	14.5	14.3	12.0	7.7	4.9	2.9	1.8	3.0	4.7	7.1	9.4	12.5

Table B.8 Mean maximum daily temperature: SILO and 18 GCMs: by month: Wagga Wagga

°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	31.2	30.9	27.4	22.4	17.4	13.5	12.5	14.3	17.3	21.2	25.7	29.2
BC 2012-2052	32.2	32.3	28.4	23.9	18.1	14.8	13.6	15.4	18.2	21.9	27.0	30.3
CM 2012-2052	32.5	32.4	27.5	22.7	17.7	14.8	13.3	15.4	18.4	21.0	26.0	30.4
CN 2012-2052	33.2	32.6	28.2	23.4	18.0	14.2	13.6	15.9	18.5	23.0	27.8	30.1
S1 2012-2052	31.9	31.6	27.9	23.7	18.3	14.8	14.0	16.2	18.5	21.3	26.1	30.0
S2 2012-2052	32.2	33.0	29.1	23.8	18.8	15.3	13.8	16.1	18.2	22.6	27.0	30.7
EC 2012-2052	33.5	32.0	28.3	23.6	18.2	13.9	13.3	16.1	17.6	22.5	27.1	30.7
EG 2012-2052	32.9	31.8	27.9	23.3	18.1	14.3	13.9	15.2	17.9	22.8	27.2	30.1
G1 2012-2052	32.3	31.3	28.7	23.7	18.0	14.5	13.6	15.7	18.4	22.4	26.6	29.8
G2 2012-2052	31.8	31.4	28.7	23.5	18.1	14.6	13.3	15.7	18.4	22.3	26.9	30.1
GH 2012-2052	33.4	32.3	28.7	23.6	18.1	14.0	13.5	16.1	17.6	21.8	27.8	30.4
HA 2012-2052	31.8	31.9	28.1	23.1	17.9	14.5	13.3	15.1	18.2	22.5	26.6	31.0
HG 2012-2052	32.5	31.5	28.3	22.9	18.1	14.0	13.5	14.6	17.6	22.6	26.8	30.0
IN 2012-2052	33.2	32.9	28.4	23.8	18.2	14.6	14.0	16.6	18.7	23.6	27.3	30.5
IP 2012-2052	35.1	32.7	29.3	24.5	18.6	15.0	13.5	15.3	18.7	23.9	27.8	31.7
MM 2012-2052	34.2	32.1	28.1	23.6	18.5	15.2	13.9	15.5	19.2	23.1	28.0	30.8
MR 2012-2052	31.9	30.8	27.9	22.2	17.7	13.9	13.2	16.0	18.5	22.0	26.1	29.5
NC 2012-2052	31.8	31.1	28.2	23.4	18.3	14.8	13.4	15.5	19.0	22.0	26.0	29.6
NP 2012-2052	34.6	33.6	29.7	24.4	18.7	15.3	14.0	16.3	18.9	23.3	29.2	31.9

Table B.9 Mean annual rainfall: SILO and 18 GCM projections: by month: Wagga Wagga

mm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	45.4	41.9	36.9	50.4	52.4	52.4	57.3	54.6	54.0	58.2	45.5	47.7
BC 2012-2052	45.6	38.3	26.2	36.1	38.3	51.4	46.6	65.9	60.0	65.8	35.3	62.0
CM 2012-2052	34.5	52.1	46.4	66.1	64.9	57.7	72.9	51.3	52.0	77.8	45.6	38.3
CN 2012-2052	41.8	49.8	48.9	39.2	59.4	39.4	45.9	46.8	45.4	40.0	44.5	36.4
S1 2012-2052	37.1	46.1	26.8	30.4	50.2	48.5	61.2	38.9	49.8	75.4	37.1	35.0
S2 2012-2052	51.6	23.8	24.1	45.4	27.5	50.1	40.4	49.3	54.5	47.9	40.7	43.4
EC 2012-2052	31.4	38.9	28.4	43.7	50.2	41.4	53.9	38.7	49.5	49.5	34.2	51.4
EG 2012-2052	43.8	49.5	43.6	32.8	43.2	48.8	41.6	60.3	49.3	36.4	44.8	73.1
G1 2012-2052	63.9	60.7	40.8	41.2	41.3	47.2	47.8	44.1	48.3	47.0	33.7	38.9
G2 2012-2052	39.8	37.7	23.0	37.5	45.5	46.2	56.0	37.7	47.0	47.6	37.8	46.9
GH 2012-2052	36.1	54.1	24.8	35.3	82.2	59.5	60.4	47.7	59.7	47.2	34.5	35.1
HA 2012-2052	50.3	31.2	45.7	38.0	63.7	50.0	43.3	46.1	49.5	48.2	46.3	41.8
HG 2012-2052	40.3	45.6	27.1	43.1	51.9	51.7	50.8	66.7	61.6	54.4	44.2	52.8
IN 2012-2052	44.6	40.1	30.3	36.5	46.1	46.3	61.9	37.9	44.0	57.9	49.5	67.9
IP 2012-2052	26.3	50.7	17.9	23.1	43.5	39.2	47.0	48.2	40.2	28.8	51.3	64.8
MM 2012-2052	42.1	60.0	35.1	42.3	64.2	45.2	46.6	59.9	41.2	63.4	35.8	47.4
MR 2012-2052	57.2	58.7	34.9	51.0	62.0	52.6	49.2	50.8	58.3	59.9	43.7	54.6
NC 2012-2052	50.7	51.7	35.9	44.0	49.9	48.9	63.7	61.3	46.9	60.9	43.2	56.7
NP 2012-2052	61.9	36.7	40.2	39.5	72.0	71.6	63.0	58.4	60.2	76.8	50.8	42.6

Table B.10 Mean minimum daily temperature: SILO and 18 GCM projections: by month: Hamilton

°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	10.6	11.1	9.9	8.0	6.5	4.8	4.4	4.9	5.7	6.4	7.8	9.2
BC 2012-2052	12.4	12.3	11.1	8.9	6.8	5.3	5.0	5.6	6.8	7.3	8.4	10.1
CM 2012-2052	11.4	12.3	10.8	8.4	7.4	5.3	5.3	5.6	6.6	7.1	8.3	10.0
CN 2012-2052	11.4	11.8	11.4	7.9	7.5	5.5	4.6	5.6	6.6	7.0	8.1	9.2
S1 2012-2052	11.2	11.7	10.6	9.1	8.1	6.2	5.6	5.8	6.7	6.8	8.5	9.5
S2 2012-2052	11.1	12.0	11.2	9.1	7.4	6.1	5.6	6.0	6.9	7.5	8.6	9.8
EC 2012-2052	11.1	11.1	10.2	8.7	7.0	4.7	4.8	5.2	5.6	6.5	7.8	9.9
EG 2012-2052	12.0	12.0	11.2	8.5	7.2	5.6	4.8	5.5	5.9	6.6	8.2	9.7
G1 2012-2052	11.3	11.6	10.7	8.8	7.1	5.5	5.0	5.2	6.2	6.9	8.4	9.3
G2 2012-2052	11.4	11.1	10.6	8.5	6.9	5.7	5.2	5.1	6.7	7.1	8.2	9.4
GH 2012-2052	11.1	11.3	11.0	8.2	7.2	5.5	5.1	5.5	6.1	6.8	8.2	9.7
HA 2012-2052	11.9	12.1	10.9	8.8	7.2	5.4	4.9	5.2	6.7	6.9	8.8	10.1
HG 2012-2052	11.7	11.1	10.5	8.2	7.3	5.4	5.1	5.3	6.2	7.0	8.1	9.5
IN 2012-2052	11.6	11.9	10.5	8.8	7.3	6.0	5.3	5.3	6.1	6.5	8.4	10.1
IP 2012-2052	12.6	11.5	10.8	8.5	7.1	5.3	5.1	5.8	6.2	6.9	8.3	10.2
MM 2012-2052	11.9	12.6	10.5	8.8	7.6	6.0	5.2	5.5	6.6	7.3	9.0	10.0
MR 2012-2052	11.3	11.8	10.0	8.4	7.1	5.2	5.2	5.3	6.5	6.7	7.8	9.7
NC 2012-2052	12.1	12.0	10.5	8.8	7.6	5.9	5.2	5.3	7.0	6.9	8.1	10.1
NP 2012-2052	8.6	9.0	8.7	6.7	5.4	3.2	2.9	4.0	4.5	5.4	6.4	7.8

Table B.11 Mean maximum daily temperature: SILO and 18 GCMs: by month: Hamilton

^oC	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	25.3	26.0	23.3	19.2	15.6	12.8	12.2	13.2	15.0	17.3	20.1	23.0
BC 2012-2052	27.4	26.9	24.4	20.5	16.2	13.5	13.0	14.4	15.6	17.6	20.7	24.1
CM 2012-2052	26.3	27.4	24.2	19.6	16.7	13.4	13.2	14.5	16.2	17.4	21.3	24.6
CN 2012-2052	27.0	27.8	24.6	20.2	16.0	13.2	12.6	14.1	16.0	18.1	20.9	24.1
S1 2012-2052	25.8	26.4	23.6	20.9	16.6	13.7	13.1	14.6	16.0	17.6	21.0	23.3
S2 2012-2052	25.6	27.7	24.6	20.6	16.8	14.0	13.1	15.0	16.2	18.2	21.4	24.6
EC 2012-2052	26.2	26.2	23.7	20.2	15.9	13.1	12.7	14.0	15.1	17.3	20.1	23.7
EG 2012-2052	26.8	27.3	24.6	20.3	16.2	13.3	12.8	13.8	15.5	17.8	21.0	24.1
G1 2012-2052	26.1	26.3	24.0	20.1	16.3	13.6	13.0	14.0	15.9	17.9	20.5	23.7
G2 2012-2052	26.5	25.8	24.0	20.6	16.1	13.4	12.6	14.1	16.0	18.1	21.2	23.9
GH 2012-2052	25.5	26.2	24.0	19.8	16.0	13.1	12.7	14.3	15.6	17.7	20.7	24.1
HA 2012-2052	26.7	27.6	23.9	20.6	16.3	13.4	13.0	14.0	16.1	18.5	21.2	24.8
HG 2012-2052	26.2	26.6	24.1	20.4	16.3	13.3	13.0	13.6	15.4	18.0	20.1	23.8
IN 2012-2052	27.1	27.8	24.3	21.0	16.5	13.8	13.2	15.1	16.1	18.6	21.6	25.3
IP 2012-2052	28.0	27.4	24.8	21.1	16.8	13.6	13.0	13.8	16.2	18.5	20.9	25.4
MM 2012-2052	27.6	28.1	24.6	20.6	16.8	14.3	13.1	14.1	16.1	18.4	22.0	25.0
MR 2012-2052	26.7	26.9	23.2	20.2	16.5	13.2	12.8	13.5	15.8	17.8	20.0	23.4
NC 2012-2052	26.7	26.9	23.9	20.6	16.9	13.5	12.8	14.6	16.4	17.9	21.5	24.5
NP 2012-2052	28.4	28.8	25.8	21.5	16.8	13.9	13.2	15.0	16.3	18.8	22.3	25.6

Table B.12 Mean annual rainfall: SILO and 18 GCM projections: by month: Hamilton

mm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Observed 1971 - 2011	35.8	26.4	39.0	49.8	57.9	69.7	78.4	82.1	76.8	63.6	53.5	47.3
BC 2012-2052	41.4	30.2	41.4	44.1	52.7	74.0	73.3	85.4	79.7	77.0	45.7	44.5
CM 2012-2052	29.5	24.6	42.4	54.3	58.8	65.8	82.2	73.3	72.9	74.3	46.5	34.2
CN 2012-2052	28.6	26.0	42.7	43.9	57.3	64.7	66.9	58.3	70.6	57.4	45.7	29.7
S1 2012-2052	36.1	37.0	40.5	38.2	59.5	75.3	79.4	67.7	66.1	55.7	52.6	44.1
S2 2012-2052	40.9	18.1	31.6	51.6	41.7	67.2	74.4	75.5	78.4	68.9	53.5	35.0
EC 2012-2052	49.0	27.8	34.2	57.9	63.3	61.5	66.1	69.8	70.1	55.6	47.8	56.2
EG 2012-2052	42.0	17.7	38.2	41.3	54.5	72.5	68.8	62.2	72.6	50.0	49.8	41.5
G1 2012-2052	39.8	31.8	37.7	52.5	53.3	60.6	69.3	73.6	67.7	58.6	49.6	37.6
G2 2012-2052	34.0	22.9	37.9	48.2	53.5	69.4	83.7	60.0	60.7	66.5	45.5	43.8
GH 2012-2052	44.8	23.7	33.0	45.9	68.7	79.2	85.3	73.3	73.1	57.7	53.4	33.7
HA 2012-2052	29.9	20.2	43.4	47.8	64.0	69.8	71.7	73.3	77.7	55.6	54.3	41.4
HG 2012-2052	44.3	22.2	36.1	43.5	64.0	69.6	82.1	82.8	88.8	58.5	52.9	41.3
IN 2012-2052	38.3	23.1	35.5	54.7	58.7	71.2	71.7	57.9	73.5	49.8	49.4	44.8
IP 2012-2052	27.1	21.6	34.0	27.8	48.1	55.3	68.4	72.0	56.0	36.3	40.7	21.1
MM 2012-2052	37.2	28.7	32.5	51.1	46.3	73.2	63.3	76.6	73.5	50.5	46.8	35.4
MR 2012-2052	35.5	32.7	45.7	44.8	50.7	71.2	68.7	79.2	75.9	65.4	51.4	39.0
NC 2012-2052	44.2	29.4	42.7	39.6	48.6	62.8	78.1	69.1	70.2	60.0	49.9	36.3
NP 2012-2052	35.4	24.8	38.5	49.6	73.5	73.7	76.7	81.9	69.0	61.3	68.6	45.8

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