Climate change impacts and adaption strategies for pasture-based industries: Australian perspective

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Highlights
In recent decades Australia has experienced warmer temperatures and, in southern Australia declining rainfall, and climate change projections indicate that these trends are likely to continue. In southern Australia, pasture growth patterns have changed with increased winter production but a contraction of the spring growing season and increased inter-annual variability of production. A range of options have been investigated to adapt farm businesses to the changing climate including feedbase, livestock management and diversification. The challenge for adaptation research is to better understand impacts and adaptation options for increases in extreme climate events, such as heatwaves, drought and intense rainfall events.

Keywords: beef, climate variability, dairy, growth rates, sheep

Background
Pasture-based livestock production systems cover approximately 50% of the Australian continent and span a broad range of climatic zones from cool, temperate in the south-east to tropical in the north, with much grazing also located in the semi-arid regions of central Australia. The Australian continent has the highest levels of year-to-year rainfall variability in the world (Love 2005), and farming systems have evolved to deal with this. Pasture-based industries in Australia are predominantly rain-fed and climate variability (particularly rainfall) has a strong influence on production and profitability (Chapman et al. 2009). Future climate projections will create greater challenges for agriculture in Australia, with increasing temperatures across the whole continent and, in southern Australia a southward movement of rainfall systems has caused a decline in winter and spring rainfall (CSIRO & Bureau of Meteorology 2015). Alongside the changes in average seasonal conditions, an increase in the frequency and severity of extreme climate events, such as drought, heatwaves and intense rainfall events is also expected (CSIRO & Bureau of Meteorology 2015). There is an important need for pasture-based livestock production to adapt to the changing climatic conditions.

Research on climate change impacts and adaptation in the Australian dairy, beef and sheep industries has gathered pace in recent years in responses to calls for action to address the climate changes that have already occurred as well as those expected over coming decades. The purpose of this review is to highlight key learnings from climate change adaptation research in Australia and make recommendations for future research directions. The focus of this review is on the pasture and implications for livestock management, and on adaptation to climate change rather than mitigation of greenhouse gas (GHG) emissions, although emissions do need to be considered as part of the adaptation response.

Climate changes already experienced and their impacts on Australian agriculture
The Australian continent has experienced an increase in average temperature (Figure 1a) and changes in annual rainfall which vary regionally (Figure 1b). While the north-west has experienced an increase in annual rainfall, most of eastern and south-western Australia has seen rainfall decline. Across southern Australia, rainfall declines have been particularly pronounced in the main growing season of April to October (CSIRO & Bureau of Meteorology 2020).

The climatic conditions experienced across Australia over the last two decades have had a substantial impact on the profitability of Australian agricultural businesses. Hughes et al. (2019) demonstrated that during the 2000-2019 period, 45% of agricultural land in Australia had farm profit levels expected in the lowest 30% of years (compared to a baseline period 1949-2019) when farm systems and commodity prices were kept constant. Much of the area with low profit was in inland Australia particularly in south-eastern and south-western Australia, where annual rainfall has been declining (Figure 1b). This highlights the urgent need

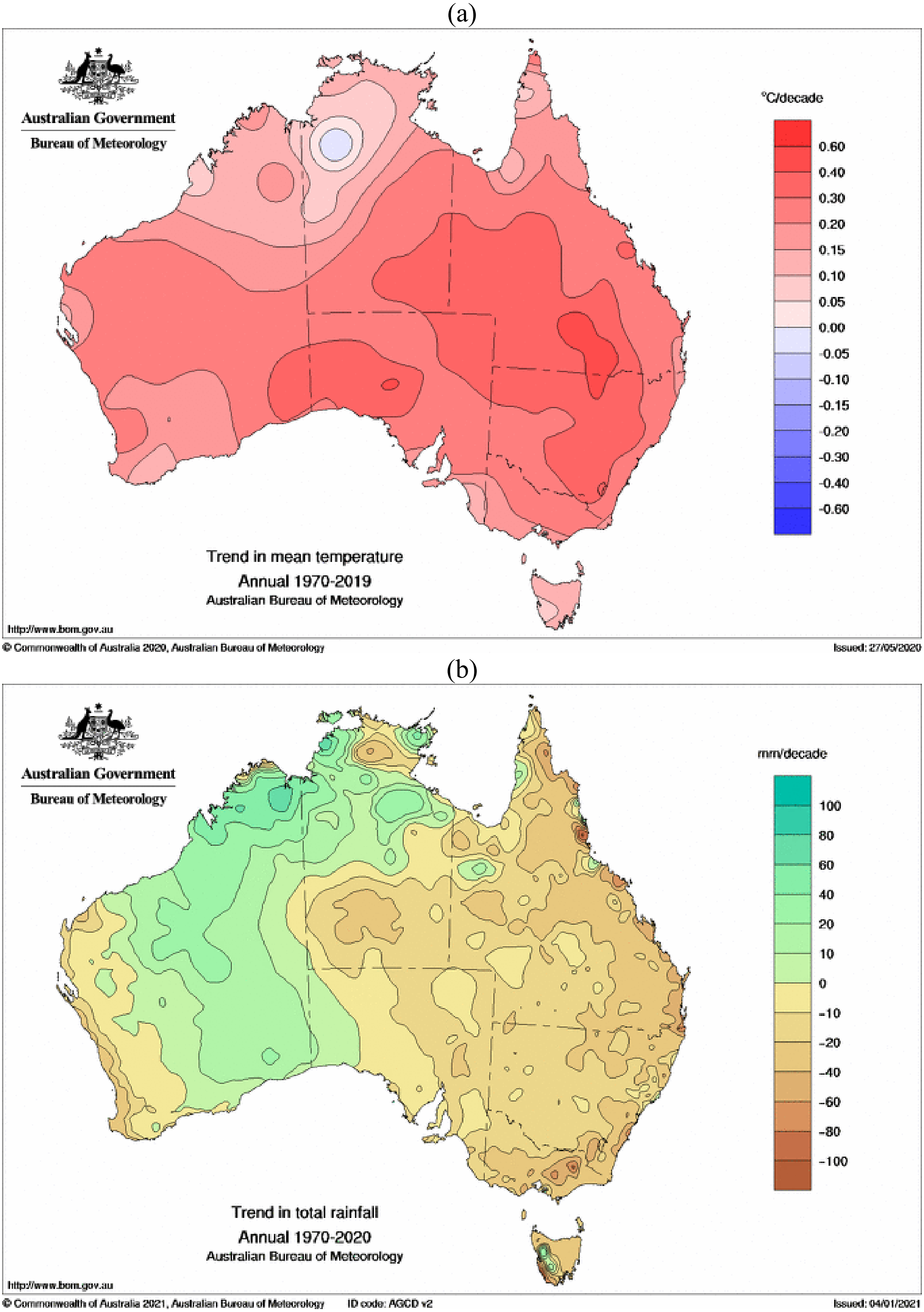

Figure 1 Trends in (a) mean temperature (°C/decade) and (b) annual rainfall (mm/decade) from 1970-2020 across the Australian continent (source: Bureau of Meteorology, www.bom.gov.au accessed 28 January 2021).

for farm businesses to adapt to the changing climate.

For pasture-based production systems in south-eastern Australia, the changes in climatic conditions have altered the growing season and trends towards higher inter-annual variability of pasture growth are emerging. In a modelling study, Perera et al. (2020) demonstrated that pasture growth rates have changed in south-eastern Australia in the period 2003-2015 compared to earlier climate periods since 1960, with increasing growth in winter but decreasing growth in spring together with increasing year-to-year variability in the autumn and spring growing seasons. Similarly, in rangeland systems of northern Australia, Cobon et al. (2019) demonstrated trends to increasing variability of pasture production since 1960.

The changes in the climate and pasture growing season in southern Australia have also challenged the persistence of pasture species suited to cool temperate, high-rainfall climate, such as perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*), leading to increased use of drought-tolerant perennial species such as cocksfoot (*Dactylis glomerata*) and phalaris (*Phalaris aquatica*) (Norton et al. 2016), as well as annual species. Lower cool-season rainfall has also caused lower water run-off volumes leading to lower inflows in farm water storages and, for irrigated pasture-systems, low water availability and/or high water prices (Rogers et al. 2017).

Coupled with these longer-term trends in climate have been the impacts of individual extreme events, such as longer droughts and greater risk of heatwaves, frost, extreme fire weather and intense rainfall, that have also had important impacts on livestock businesses. Examples include severe flooding in north Queensland causing cattle death, loss of infrastructure and damage to pasture (The State of Queensland 2019), heat stress in livestock (e.g., Osei-Amponsah et al. 2020), extension of the frost window in south-eastern Australia (Crimp et al. 2016) and bushfires (CSIRO & Bureau of Meteorology 2020). Adaptation to a changing climate must recognise the multitude of climate factors that affect pasture-based production systems and their impacts.

Future climate scenarios for analysis of impacts and adaptation

Climate change projections for Australia broadly follow similar trends to the observed changes discussed above, with increasing temperatures and atmospheric carbon dioxide concentrations projected across the continent, along with declining rainfall in southern Australia mainly in the winter and spring seasons (CSIRO & Bureau of Meteorology 2015). For example, in Victoria under high GHG emissions scenarios (representative concentration pathway 8.5), by 2050 the temperature is expected to increase 1.4-2.4°C relative to the 1986-2005 baseline with an 8-14% decrease in annual rainfall most of which will occur in winter and spring (The State of Victoria 2019).

Across Victoria, the observed warming and rainfall declines over the last two decades are at the hot and dry end of the range of climate change projections (The State of Victoria 2019), indicating that projections may be overly conservative. The comparison of these observed trends in relation to the range of climate change projections is important to consider when selecting what projections to use for the assessment of climate change impacts and adaptation options. The ‘average’ or ‘median’ climate change projections are often used in such analyses e.g., Cullen et al. (2009), but it is increasingly important to also examine future climate scenarios at the more extreme end of the warmer temperature and lower rainfall projections, as they better reflect the recent observed climate changes. A number of studies have compared climate change impacts using ‘median’ or ‘hot and dry’ scenarios and the latter scenarios show much greater impact (Meyer et al. 2017; Ghahramani et al. 2020).

Projections for increases in extreme climate events include longer fire season, more intense heavy rainfall, more heatwaves and, in southern Australia, more time in drought conditions (CSIRO & Bureau of Meteorology 2015). These must also be captured in future climate scenarios for climate change analysis, as they alter the distribution of rainfall through the year not only the total amount. Harrison et al. (2016a) compared simulated pasture production in future climate scenarios created by scaling historical climate (termed the ‘gradual’ approach) with another approach that used a process that achieved the same overall monthly climatic changes but also captured increases in extreme climate events (e.g., more rainfall in fewer, larger events and more heatwaves, termed the ‘variable’ approach). The variable approach led to lower annual pasture production than the gradual approach with higher year-to-year variability, highlighting the importance of incorporating extreme climate events into climate scenarios. The ability of farm systems models to simulate the impact of climate extremes on pastures is also limited, for example the models do not typically simulate plant death (e.g., Cullen et al. 2009) which may lead to longer-term changes in species composition and pasture productivity.

Climate change impacts on pasture productivity

Numerous studies have simulated the impact of future climate scenarios on pasture growth patterns around Australia. In higher-rainfall regions of southern Australia, higher pasture growth rates in the winter-early spring period, when soil moisture is still available, are predicted along with a contraction of the spring growing season due to declining rainfall and high temperatures (e.g., Cullen et al. 2009; Moore & Ghahramani 2013). While the pattern of change is quite consistent, there are some regional differences with production and profitability of pasture-based livestock production predicted to be more impacted in the lower rainfall, warmer regions compared to the cooler, higher rainfall areas (Moore & Ghahramani 2013). Pasture production may increase in the high rainfall, cool temperature regions like north-west Tasmania (Phelan et al. 2015; Harrison et al. 2017), but this is a small proportion of the land used for pasture-based production. The shorter growing season in southern Australia will also challenge the persistence of some temperate pasture species, requiring a re-evaluation of the species and cultivars that are best suited (Norton et al. 2016). In rangeland systems of northern Australia, trends in pasture productivity under future climate scenarios are harder to discern because of the low and highly variable grass production in much of the region as well as there being no clear signal for rainfall change in the future climate projections (McKeon et al. 2009).

To illustrate the impacts of a range of historical and future climate scenarios on pasture growth patterns in southern Australia, an example of an annual ryegrass (*Lolium rigidum*)-subterranean clover (*Trifolium subterraneum*) pasture on a cracking-clay soil was simulated at Violet Town in northern Victoria (-36.63S, 145.72E) and is shown in Figure 2. Six different climate scenarios (each consisting of 20-year intervals) were investigated to compare pasture growth patterns under historical and future climate scenarios:

- Baseline climate – 1986-2005 climate data from Bureau of Meteorology. This period is used as the baseline climate to be consistent with the methods for the climate projections.
- Recent climate – 2000-2019 climate data from Bureau of Meteorology.
- 2030 Median climate – applied ‘mid range’ projections for temperature and rainfall change at 2030.
- 2030 Hot and Dry climate – applied ‘high range’ (90th percentile) projections for increasing temperature and declining rainfall at 2030.
- 2050 Median climate – applied ‘mid range’ projections for temperature and rainfall change at 2050.
- 2050 Hot and Dry climate – applied ‘high range’ (90th percentile) projections for increasing temperature and declining rainfall at 2050.

A summary of the temperature and rainfall for each of the scenarios is provided in Table 1. Climate change projections for rainfall and temperature were based on dynamically downscaled global climate model projections that were sourced from the Victorian Climate Change Projections 2019 (The State of Victoria 2019). The future climates were created using the variable method of Harrison et al. (2016a). All the future climate scenarios assumed a high GHG emission pathway (Representative concentration pathway 8.5, IPCC 2014) because the observed climate changes in Victoria are most consistent with this pathway (The State of Victoria 2019). Atmospheric carbon dioxide concentrations were assumed to be 350 ppm for Baseline, 380 ppm for Recent, 450 ppm for 2030 scenarios and 530 ppm for 2050 scenarios. Pasture growth patterns were simulated using the Grassgro biophysical model (Moore et al. 1997), which has been previously applied

Table 1 Long-term average rainfall (mm) and temperature (°C) statistics for the Baseline and Recent scenarios, together with rainfall (percentage) and temperature (°C) changes relative to Baseline (1986-2005) for the future projections at Violet Town, Victoria.

Season	Baseline	Recent	2030 Median	2030 Hot and Dry	2050 Median	2050 Hot and Dry
	Average rain (mm)		Rainfall change from Baseline (%)			
Summer	114	132	-2	-25	-3	-5
Autumn	139	115	-6	-21	-10	-22
Winter	227	181	-10	-17	-16	-24
Spring	184	133	-15	-20	-22	-28
	Average temperature (°C)		Temperature change from Baseline (°C)			
Summer	21.0	21.9	+1.1	+1.8	+2.1	+2.9
Autumn	15.1	15.3	+1.0	+1.3	+1.8	+2.5
Winter	8.6	8.5	+0.8	+0.9	+1.3	+1.6
Spring	13.9	14.5	+1.4	+1.8	+2.4	+3.1

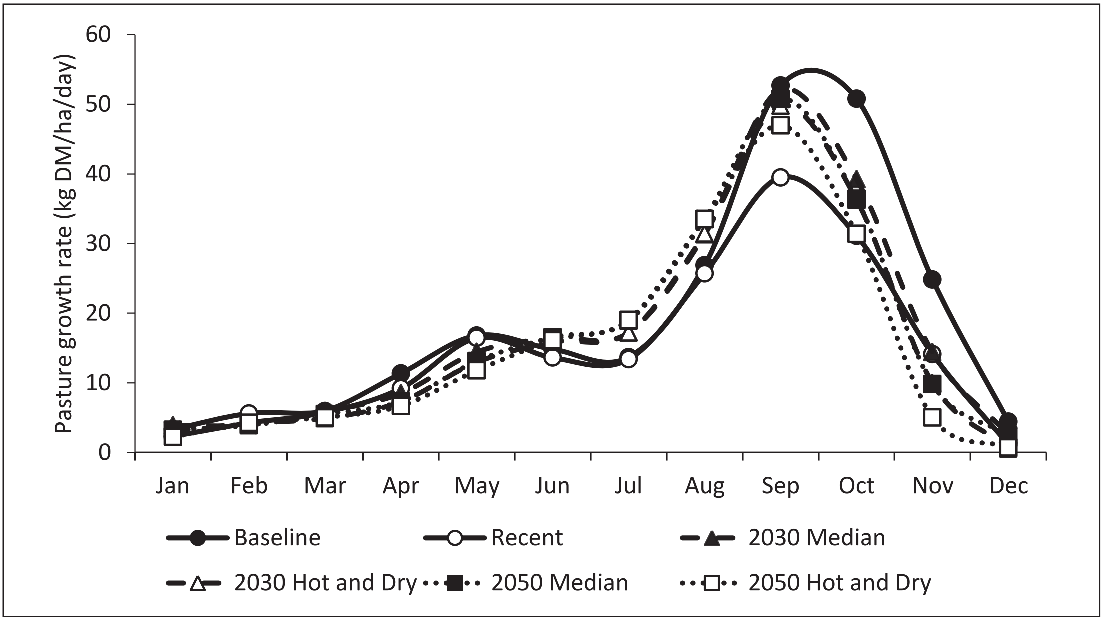

Figure 2 Simulated monthly average pasture growth rates (kg DM/ha/day) at Violet Town, Victoria, Australia, under two historical and four future climate scenarios (unpublished data).

to the analysis of climate change impacts in southern Australia (e.g., Moore & Ghahramani 2013).

Comparing the Baseline and Recent scenarios, annual rainfall had declined by 15% with most of the decline in winter and spring, while temperatures had increased in summer and spring. The 2030 and 2050 projections reflect a continuation of the warmer and drier trends, with greater changes in the ‘hot and dry’ scenarios.

Compared to the Baseline scenario, the Recent and future climate scenarios showed a trend towards increased winter growth rates but a contraction of the spring growing season (Figure 2). Annual pasture production was highest in the Baseline scenario (average 7.0 t dry matter (DM)/ha, range 3.5-11.4) and was lowest and most variable in the Recent scenario (5.4 t DM/ha, range 2.3-8.3). The future climate scenarios were intermediate between the Baseline and Recent scenarios with average values of 6.4, 5.9, 6.2 and 5.6 t DM/ha for the 2030 Median, 2030 Hot and Dry, 2050 Median and 2050 Hot and Dry scenarios, respectively. The low growth rates in the Recent scenario highlight the difficult seasonal conditions experienced in the period 2000-2019 and may indicate that the impacts of climate change on pasture growth are occurring sooner than anticipated. The 2030 and 2050 climate scenarios simulated higher pasture growth than the Recent climate scenario in the winter and early spring months due to higher temperatures and increased atmospheric carbon dioxide concentrations.

While understanding climate change impacts on pasture growth patterns provides a sound basis for determining the need to adapt and informing adaptation options, it is also useful to put it into a whole farm context and estimate economic impacts. Relatively small impacts on pasture growth and utilisation can have substantial impacts on farm profit (e.g., Moore & Ghahramani 2013; Harrison et al. 2017), as it requires increases in the amount of supplementary feed consumed which is usually at a high price in drought conditions.

Adaptation options

An extensive range of adaptation options for pasture-based production systems have been assessed across Australia, including options to change the feedbase, improve tactical decision making, adjust stocking rates and policies, and add flexibility or diversity to the production system. The adaptation options published in the scientific literature applicable to Australian grazing systems are summarised in Table 2, where consideration has been given to the opportunity presented but also the limitations of the adaptation response.

Some adaptations tested can be considered as the adoption of current best management practices to make the most of current climatic conditions, such as increasing soil fertility to maximise the amount of pasture growth for the available soil water. Other adaptations are designed to make better use of a warmer and drier climate, for example by incorporating pasture species with more summer-active growth patterns.

Adjusting stocking rates and policies to the changed patterns of pasture growth (either through climate or from adoption of alternative forages) will be required as part of a system-level response to climate change. There is evidence that implementing a combination of adaptations to feedbase and animal management on-farm can mitigate the impacts of projected climate change on farm profitability (Ghahramani & Moore 2015).

With increasing inter-annual climate and pasture growth variability, tactical management (such as adjusting stocking rates and selling times or purchasing supplementary feeds) has an important role to play in adaptation. This is not only to reduce the risk in years with low pasture production, but to take advantage of years with high pasture growth. Seasonal forecasts provide some information for tactical management, and this is being combined into new tools that integrate seasonal forecasts with monitoring of pasture mass (e.g., Ag360, https://ag360.com.au) or stored soil moisture content (e.g., Farming Forecaster, https://farmingforecaster.com.au).

Diversification of farm businesses in response to climate risk has also received attention as an adaptation option to climate change. Spatial diversification relies on farming in different climatic regions to reduce the risk of poor seasonal conditions (Nguyen-Huy et al. 2020). On mixed farms in low-rainfall regions, increasing the proportion of livestock has shown to be beneficial as the returns are less risky with livestock providing better returns than crops in poor years (Ghahramani et al. 2020). There are also emerging opportunities for farmers to earn income by reducing GHG emissions through the Australian government's Emissions Reduction Fund (ERF) by implementing specific management practices on-farm, although a number of studies have shown that carbon income is relatively low compared with the costs of implementing an ERF mitigation option (Alcock et al. 2014; Harrison et al. 2016b).

In addition to the adaptation options listed in Table

Table 2 Summary of published adaptation responses for pasture-based production systems in response to a changing climate in Australia.

Adaptation	Opportunity	Limitation	Reference
Feedbase			
Increase soil fertility	Maximise the pasture produced for water available	Current best practice, does not apply to all regions	Ghahramani & Moore 2013, 2015
Deeper rooted and heat-tolerant temperate species	Extend the growing season in spring-summer shoulder, improved persistence	No additional production in failed springs	Cullen et al. 2009; Ghahramani & Moore 2013, 2015
Summer-active pasture species (e.g., tropical grasses)	Utilise summer rainfall	Lower feed quality and may create winter feed gap	Bell et al. 2013
Forage cropping to fill feed gaps	Utilise crops with high growth rates and water use efficiency	Forage conservation costs and losses	Pembleton et al. 2021
Livestock management			
Altered stocking rates	Lower stocking rates to match reduced pasture production	Reduced ability to capitalise on good seasons	Ghahramani & Moore 2015
Adjusted stocking policies	Change calving/lambing to fit with changed seasonal pattern of pasture growth	None	Harrison et al. 2017
Technology and Infrastructure			
Use of seasonal climate forecasting to improve tactical management	Early decision making such as de-stocking or purchasing supplementary feed	Lack of seasonal climate skill in some regions and at times of year	Ash et al. 2007; Cobon et al. 2020
Trees on-farm, or other shade infrastructure	Trees or hedge rows on-farm to provide shade and shelter for extreme conditions	Unprofitable compared to livestock production	Sinnett et al. 2016
Diversification			
Change enterprise mix	Shift in balance between livestock and crop in mixed farming	Large investment to support multiple industries	Ghahramani et al. 2020
Spatial diversification	Climatic risk spread using multiple locations	Large investment required	Nguyen-Huy et al. 2020
New products	Payments for carbon sequestration in soils and trees	May be less profitable than livestock production	Doran-Browne et al. 2018

2, a range of other adaptations are being practised on-farm in response to climate changes. The focus of many of these options is to increase the flexibility of the farm system to adapt to year-to-year variability. The adaptation options include:

- Increasing stock shade and shelter for extreme conditions;
- Upgrading farm water infrastructure (increasing dam size, piping water and reducing wastage);
- Carrying larger fodder reserves;
- Fans and sprinklers in sheds and yards (dairy) and increasing natural shade for more extensive grazing systems;
- Trading livestock within and between businesses to provide flexibility in stocking rates (beef and sheep); and
- Improved business management to plan for income variability.

While much of the research on climate change adaptation has utilised farm system modelling approaches, such approaches are not well suited to examine the impacts of 'episodic' extreme climate events such as floods caused by intense rainfall, or bushfire. Such extreme events are not easily predicted due to their temporal and spatial variability, and farm systems models are not well parameterised to capture the impacts – for example, the effects of flooding, fire or drought on pasture species composition. Risk management approaches are needed (Cobon et al. 2009) that formally identify the climate risks of consequence to the farm business, identify the choices available and calculate the economic outcomes of each choice. These can then guide the farm business in seeking more detailed information and data from supply chains through to climate forecasts.

Conclusions

Australian pasture-based production systems have endured difficult climatic conditions over the last two decades, including increasing temperatures, growing season rainfall declines, multiple year droughts and climate extremes. These climatic changes are consistent with the future climate projections, although the changes that have occurred are at the 'hot' and 'dry' ends of the current temperature and rainfall change projections. Adaptation to the changing climate is a high priority for these industries and it is being investigated in research and practised on-farm.

Developing appropriate methods for constructing future climate scenarios is a key consideration for climate change impact and adaptation analysis. The range of future climate projections does need to be considered, but particular emphasis should be placed on projections that reflect recent trends, for example in southern Australia this points to scenarios at the warmer and drier end of the projections. Long-term gradual changes in the average climate (e.g., gradual warming or rainfall declines) may also underestimate the climate change impacts if they do not consider the changes in extreme climate events and how these influence the inter-annual variability of pasture production. Leading on from this, analysis of adaptation options using farm systems modelling approaches are limited in their prediction of the impacts of climate extremes because the responses may not be known and/or built into the models, so other approaches, such as risk management, need to be better integrated into this research.

ACKNOWLEDGEMENTS

The authors acknowledge the funding from Meat and Livestock Australia Donor Company, The University of Melbourne, University of Tasmania and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the 'Nexus' project through which these ideas have been developed.

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