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Modelling the impacts of and adaptation responses to climate variability and change in Australian cropping systems

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Abstract: In this paper we report on agronomic modelling of continuous cropping at seven sites across Australia, examining yield variations in response to climate conditions over the last fifty years and over the last ten years, and comparing these with potential yield variations under a possible future (2030) climate. In this approach we model a number of adaptation options nominated by farmers within the regions and examine the yield implications of including these options.

The APSIM crop model was used to examine the impacts of climate variability and change on current and possible future yields at different cropping regions across Australia, and to examine regionally specific adaptation options in response to a moderate future climate change scenario.

Two clear trends emerged from the comparison between recent (1998-2007) and long-term (1958-2007) yields: simulated median yields from Western Australia have fallen by an average of 24.7% over the last ten years. A similar trend was modelled at one South Australian site. This decrease is largely in response to rainfall over the last ten years being near the lowest on record (CSIRO, 2007). In contrast, yield increases have been simulated at the remaining sites in South Australia (average median increase of 5.8% above long-term estimates) and at the site in New South Wales (median increase of 15.3% above the long-term estimate).

This examination of impacts of climate change on future yields and of the effectiveness of nominated adaptation options revealed that further declines in yield may occur across all case study sites in response to further projected declines in rainfall. At most of the APSIM study sites the introduction of shorter growing season wheat varieties or changing from wheat to barley were not effective adaptation options to mitigate yield losses. However, introducing a fallow phase into a continuous wheat rotation served as an effective method to combat climate change related yield losses. Introducing a fallow into rotations under current climate conditions was also likely to increase productivity in some regions although implementation of this adaptation option will require cost-benefit analysis on a farm by farm basis. In a mixed cropping system under moderate climate warming removing higher risk crops such as canola from the rotation also proved an effective adaptation option.

Keywords: *Adaptation options, APSIM, climate change, cropping systems*

1. INTRODUCTION

Farming systems in Australia are sensitive to both long-term climatic conditions and year to year climate variability. This sensitivity is reflected in the timing and type of crops sown, average yields and yield variability, grain quality, size and frequency of area cropped, preferred soil types, management systems and technologies used, input costs, product prices and natural resource management strategies. Climate related agricultural productivity losses in 2006-07 were estimated at $A2.4 billion (about 6% of total agricultural productivity) (ABARE, 2008). Future climate change scenarios predict greater exposure to climate extremes and hence increased risk to farm productivity and profitability, particularly if current farm management systems do not adapt adequately to the changing climate (Howden et al., 2007).

Wheat is a key crop in Australian agriculture both for domestic consumption and as an agricultural export (ABARE, 2008). The likely effects of climate change in wheat growing regions are of great importance, as are investigations of regional specific adaptation options to offset likely impacts. Much recent adaptation research has concentrated on understanding the value and feasible development of broad-scale adaptation options for agricultural production (Easterling et al., 2007; Howden et al., 2007). The success or failure of these broad-scale adaptation options will depend largely on regional climate and prevailing soil conditions, and will require regionally specific evaluation processes to determine their efficacy.

Computer simulation software plays a key part in identifying regionally specific agricultural sensitivities and exploring potential adaptation options. In this paper we outline the integration of crop simulation software, climate change science and expert farmer knowledge to simulate the impacts of climate on production and to examine adaptation options with respect to their likely efficacy in possible future climate conditions.

2. MATERIALS AND METHODS

The Agricultural Production Systems Simulator (APSIM) (Keating et al., 2003) was used in this study. APSIM simulates complex agronomic and edaphic processes including soil water and nitrogen balances, climate inputs, on-farm management decisions, and crop phenology including growth and yield. APSIM has been extensively validated and used on many Australian soils under a variety of Australian cropping regimes.

Seven study sites were located across Australian wheat growing regions: at Morawa, Mullewa and Yuna in Western Australia (WA), at Lameroo, Paskeville and Tarlee in South Australia (SA) and at Grenfell in New South Wales (NSW) (Figure 1).

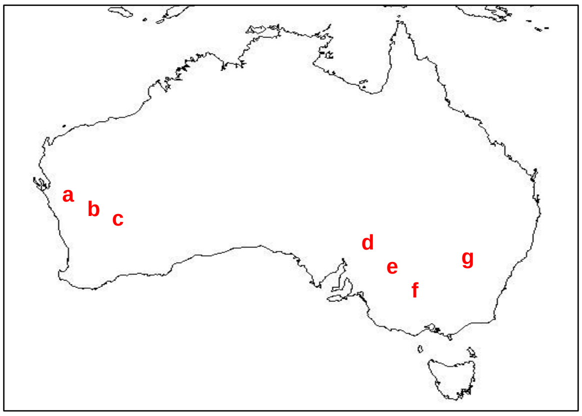


Figure 1 Approximate location of study sites across Australia: Yuna (a), Mullewa (b) and Morawa (c) in WA; in SA Paskeville (d), Tarlee (e) and Lameroo (f) in SA; and Grenfell (g) in NSW.

For each study site, APSIM was used to simulate agronomic processes and estimate yields for one paddock under four different climate scenarios: long-term, present-day, and, under a 2030 climate with either current management practices or regionally specific adaptation options. The WA and SA simulations were continuous wheat systems, while at the NSW site a continuous cropping system which was predominantly wheat, with some lupin and canola, was simulated.

APSIM was configured to be representative of the regional conditions at each study site: climate and soil data chosen were broadly representative of the local conditions, while cropping practices (e.g. timing and frequency of sowing and fertiliser events, soil cultivations, etc.) were supplied by local farm managers and were considered to be typical of farms within the region.

Climate data from the Australian Bureau of Meteorology were used in the long-term and present-day simulations for 1958-2007 and 1998-2007 respectively. Local farm managers supplied records of crop rotations (where relevant) and recent yields were used to benchmark the APSIM simulations within the study regions.

For the simulations of likely yields under a possible 2030 climate the present-day climate files were modified, using median projection values from the CSIRO (2007) Technical Report (Table 1). Atmospheric CO_2 concentrations were set at 440ppm.

Table 1 Changes from present-day climate records in temperature and rainfall used in 2030 APSIM simulations

Location	**Change in maximum temperature (°C)**	**Change in minimum temperature (°C)**	**Change in rainfall**
Morawa, WA	+ 1.8	+1.5	-8%
Mullewa, WA	+1.8	+1.5	-8%
Yuna, WA	+1.8	+1.5	-8%
Lameroo, SA	+1.3	+1.0	-8%
Paskeville, SA	+1.3	+1.0	-7%
Tarlee, SA	+1.3	+1.1	-8%
Grenfell, NSW	+1.5	+1.5	-15%

Potential adaptation options were identified by the participating farmers and modelled in the APSIM simulations. Most frequently nominated potential adaptation options included introducing a wheat cultivar with a shorter growing season, or fallowing one year in three. In WA and SA a third adaptation option was to replace wheat with barley; barley was an attractive adaptation option for some because it can be sown later in the season and still produce profitable yields. In NSW the third adaptation option was to remove higher-risk canola from the rotation. For each region these adaptation options were applied to the future climate simulation.

3. RESULTS

3.1. Long-term and present-day yield comparison

At the WA sites and at Lameroo (SA) median yield losses of between 17.0 and 28.4% were simulated from the long-term to the present-day, while for the remaining sites in SA and NSW small median yield gains (2.9 to 15.3%) were simulated (Table 2).

Table 2 Long-term, present-day and 2030 median yield estimates

	Median yield (kg/ha)				
Site	**Long-term**	**Present-day**	**2030**	**Median yield change long-term to present-day**	**Median yield change present -day to 2030**
Morawa, WA	2934	2320	1821	-20.9%	-21.5%
Mullewa, WA	2668	1911	1643	-28.4%	-14.0%
Yuna, WA	2070	1658	1668	-24.8%	+0.6%
Lameroo, SA	2057	1707	1573	-17.0%	-7.9%
Paskeville, SA	2631	2706	2627	+2.9%	-2.9%
Tarlee, SA	3864	4198	4002	+8.6%	-4.7%
Grenfell, NSW	2160	2491	2150	+15.3%	-13.7%

At the WA study sites, including Morawa (Figure 2a), and at Lameroo, yields estimated in the last ten years were lower than those simulated over the longer term. At Paskeville (Figure 2b), average and below-average yields simulated under the present-day climate were generally slightly higher than those simulated in the long-term, however above-average yields were considerably lower. At Tarlee (Figure 2c) and Grenfell (Figure 2d), yields simulated under present-day climate conditions were generally higher than those simulated using the long-term climate data. While this increase was fairly uniform at Tarlee, the likely improvement in simulated yields decreased as the estimated yield improved at Grenfell.

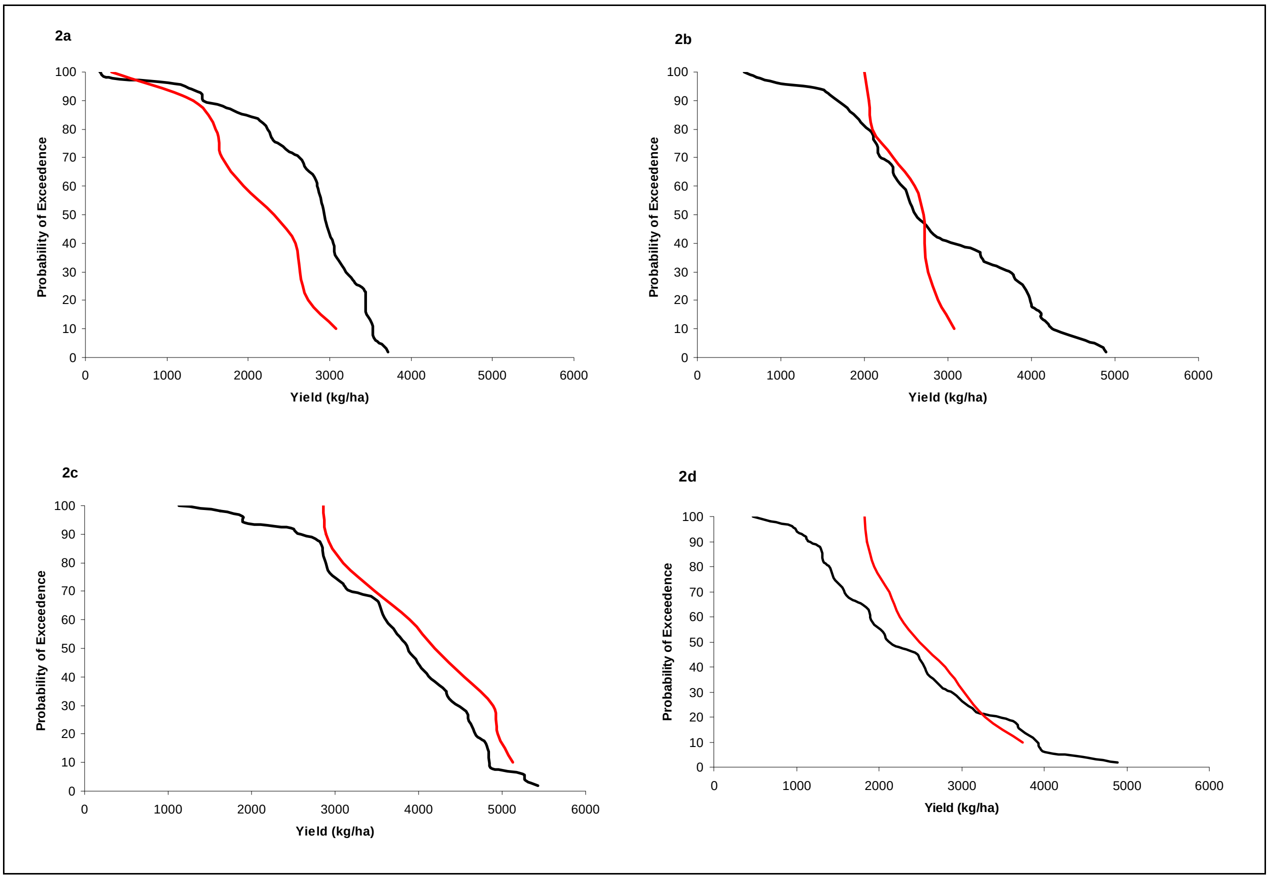
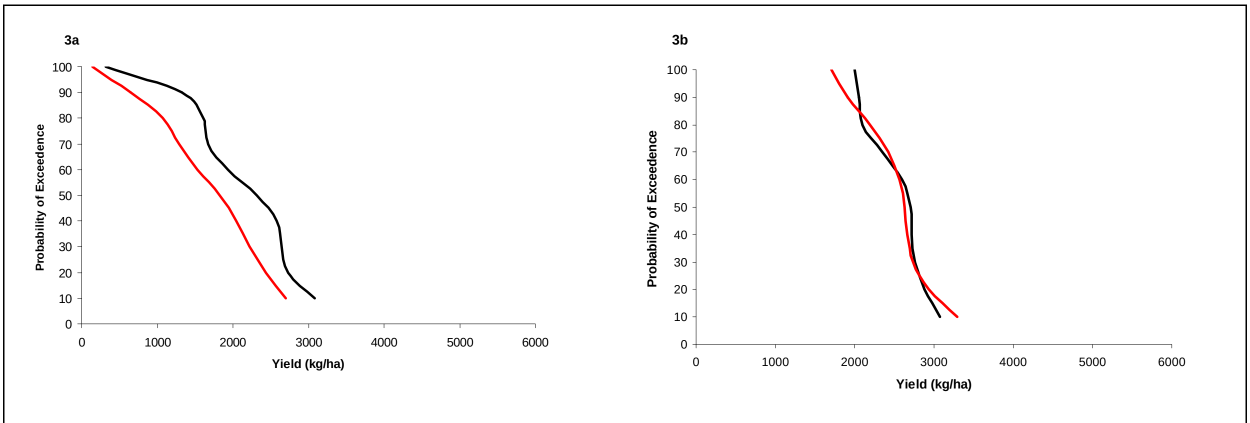


Figure 2 Long-term (black) and present-day (red) yields simulated at a) Morawa (WA), b) Paskeville (SA), c) Tarlee (SA) and d) Grenfell (NSW).

3.2. Current management strategies in a possible future climate

At all sites but Yuna, median yields were simulated to decline from the present-day simulation to the 2030 simulation with unchanged management. Losses ranged from -2.9% at Paskeville to -21.5% at Morawa. At Yuna median yields were simulated to increase by 0.6% under a 2030 climate (Table 2).

Yield reductions were estimated for most years at four sites in 2030 under an unadapted crop management strategy. These reductions occurred at Morawa (Figure 3a) and Mullewa (WA), Lameroo (SA), and Grenfell (NSW) (Figure 3d). Simulations at Paskeville (SA) (Figure 3b) and Yuna (WA) showed no significant change in yield between present-day and 2030 climate, while the simulation at Tarlee (SA) (Figure 3c) indicated that yields in average years were likely to decrease under a future climate but yields in very low and exceptionally high-yielding years were unlikely to change significantly from those simulated in present-day conditions.



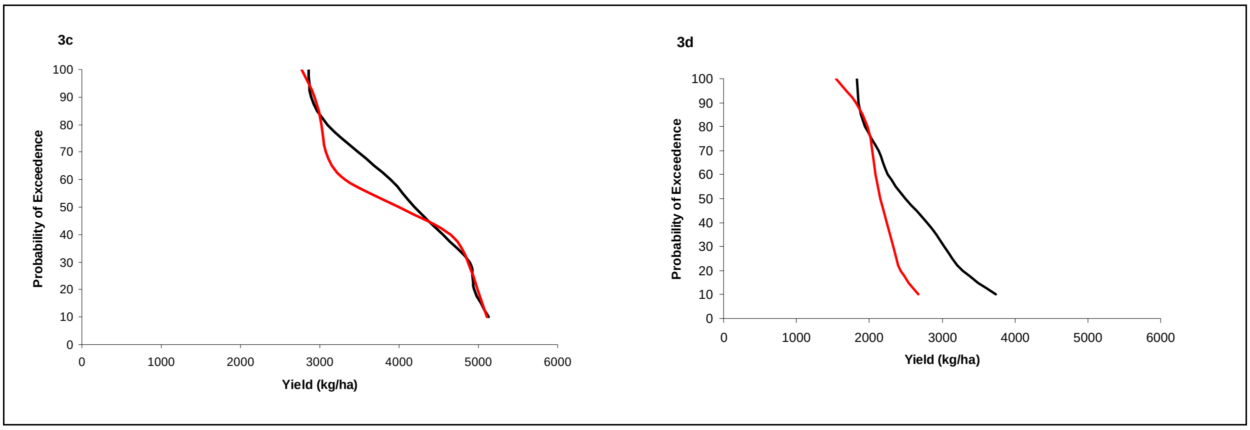


Figure 3 Yields simulated under current management practices for present-day (black) and 2030 (red) climates at a) Morawa (WA), b) Paskeville (SA), c) Tarlee (SA) and d) Grenfell (NSW)

3.3. Adaptation options in a possible future climate

Simulations at the three WA sites and at the Paskeville and Tarlee sites indicated that in a 2030 climate introducing a fallow into the rotation was effective at offsetting potential climate change related yield losses. At all sites introducing a fallow also increased yields above those estimated in present-day conditions for at least some years. Results from Morawa (Figure 4) are representative of these five study sites.

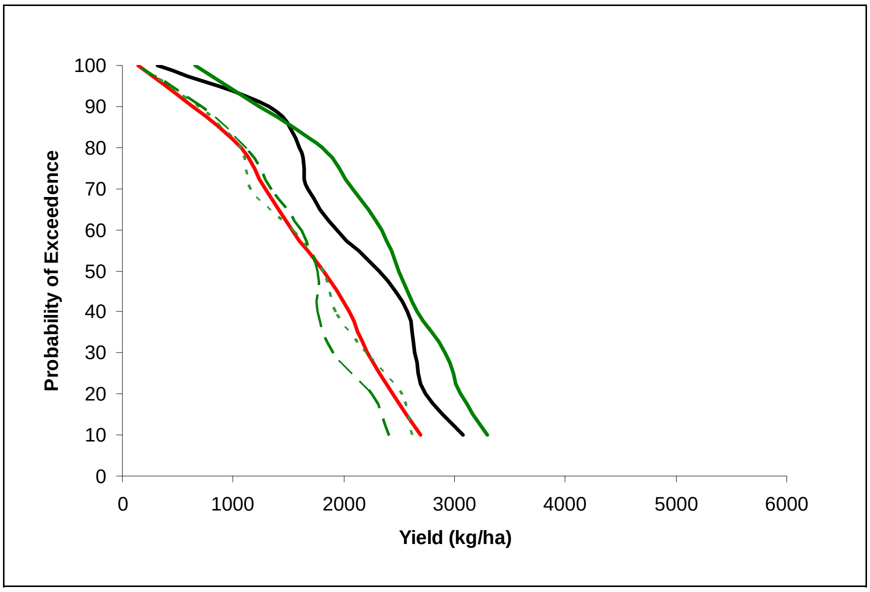


Figure 4 Yields simulated at Morawa (WA) under present-day conditions (black line), and 2030 climate and current management (red line), a short wheat cultivar (green dotted line), barley (green dashed line), and with a fallow every third year (green line).

Simulations at the Lameroo site (not shown) indicate that all three adaptation options provided some benefit in median yield above the unadapted 2030 simulation (fallowing: +7.7%, short wheat cultivar: +11.7%, barley: +14.4). As well, the introduction of a fallow increased yield estimates above present-day rates in average and above-average years.

In the mixed cropping simulation at Grenfell, NSW (Figure 5) removing canola from the rotation was the most attractive adaptation option, as it increased yields over the unadapted management strategy in all but extremely poor yielding years. Introducing a fallow or a shorter wheat cultivar into the rotation had only limited benefits.

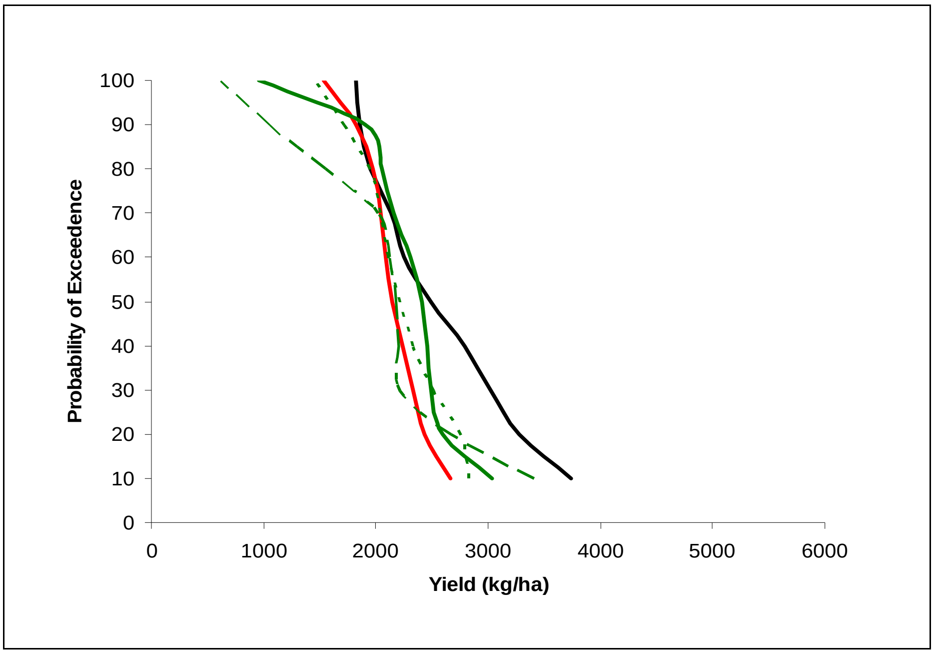


Figure 5 Yields simulated at Grenfell (NSW) under present-day conditions (black line), and 2030 climate and current management (red line), a short wheat cultivar (green dotted line), a fallow every third year (green dashed line), and with canola removed from the rotation (green line).

4. DISCUSSION

4.1. Long-term and present-day yields

Different yield responses to recent changes in climate variability were estimated for different regions across Australia. At the three WA sites and at Lameroo, lower yields over the last ten years than those from the long-term simulations were likely to be a reflection of the current warming and drying trends experienced across large parts of Australia (CSIRO, 2007). No clear trend was simulated at Paskeville, however yields in above-average years were much higher under the long-term than the present-day climate, which may also be a reflection of recent warming and drying climate trends. At the Tarlee and Grenfell sites, APSIM simulations predicted increases in yields under present-day conditions, which were likely to be a consequence of reductions in yield losses associated with reducing occurrences of frost damage.

4.2. Present-day and possible 2030 climate yields with unaltered management

Compared to present-day simulations, yield estimates modelled under a possible future climate indicated either small yield gains or larger yield losses. Potential yield gains are likely to result from ongoing reductions in frost risk, whereas yield losses are likely to be due to continuing water and temperature stresses. Rainfall estimates used in the 2030 climate simulations were based on present-day rainfall patterns, which are likely to alter into the future in many regions (CSIRO, 2007). The effects of these potential changes to annual rainfall patterns have yet to be tested.

There were no large yield gains simulated by continuing present-day management strategies into a possible future climate. The yield responses to climate change modelled were spatially diverse, as a result of regional climatic, edaphic and management differences.

4.3. Adaptation options in a 2030 climate

In continuous wheat systems under a possible 2030 climate introducing a fallow into the rotation increased yield estimates compared to an unaltered management strategy, and in many cases increased yield estimates above those simulated for present-day conditions. The introduction of a fallow phase is likely to have enhanced yield performance in lower rainfall years by offsetting projected yield losses (Crimp et al, 2007). Introducing a fallow into the continuous mixed cropping system produced estimates of higher yields than under an unchanged management strategy only in exceptionally high-yielding years, suggesting that in most years a fallow period was not a particularly beneficial adaptation option for this system.

It is possible that at some sites regular fallowing may be a useful management tool that could be used currently and into the future, however an analysis of gross margins would need to be performed to assess in which paddocks, if any, fallowing would be profitable. Because of differing on-farm management practices required at fallowing, (such as tractor use, fertiliser and herbicide applications) gross margins must be calculated on a farm by farm basis in order to estimate the net benefit or cost of introducing a fallow.

Crimp et al (2008) analysed gross margins for three Australian mixed cropping systems under a possible 2030 climate and found that apparent yield benefits did not translate into economic benefits, largely because the productivity gains following a fallow period were not large enough to compensate for increased paddock maintenance costs during and after the fallow.

In most simulations, replacing wheat with another crop (in this case barley) did not result in improved yields. Further analyses with alternative crops are required. Using a shorter wheat cultivar often resulted in simulated yields similar to those from an unchanged management simulation (e.g. Figure 4), or higher yields in particularly good years only (e.g. Figure 5). While large productivity gains from introducing a shorter cultivar were unlikely, Crimp et al (2008) found for some systems it may become an attractive adaptation option, as gross margins were higher than in the unaltered management simulation.

In the mixed cropping system under a possible 2030 climate, removing high-risk canola crops from the rotation increased yields above those from the unaltered management simulation in all cases except in especially low-yielding years. As well, in most below-average years removing canola produced yield estimates that were better than present-day yield estimates, suggesting a current management strategy for farmers around the Grenfell region could be to remove higher risk crops such as canola from the permanent rotation and use them as opportunistic crops only.

5. CONCLUSIONS

Yields simulated using present-day climate data differed from those simulated using long-term data. These differences varied regionally and are likely to be the result of spatial differences in observed warming and drying trends on underlying paddock management and edaphic and climatic systems.

Simulations of cropping systems in 2030 under a moderate climate change scenario, modelled without adapting current management regimes, suggested that while some improvements in productivity might be achieved, overall larger reductions in productivity in response to warmer and drier conditions were to be expected. Applying the adaptation strategies developed using farmers' expert agricultural knowledge showed that some production decreases could be ameliorated. However, if the climate change experienced in 2030 were greater than that modelled in these simulations these yield estimates and adaptation options may no longer be valid. In some instances the adaptation options examined may also improve yields in present-day climate scenarios above those achieved with current management regimes.

In general, some crop management adaptations will be significant in maintaining or increasing yields under variable and changing climate conditions. Different adaptation options will be required across different regions and crop management systems: the modelling techniques used here were effective at highlighting both those adaptation options which are likely to assist farmers adapt to a given climate change scenario, and also those which are likely to be less efficacious.

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