On-farm management in a changing climate: A participatory approach to adaptation

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Take Home Messages

- There is firm evidence that, in addition to climate variability, there are also changes (trends) in key climate indices (i.e. rainfall and temperature) resulting from human activity, which will have important consequences on agricultural production in Australia.
- Good risk managers need to consider both climate variability and change in their on-farm plans in order to ensure future sustainability.
- Under changed climate conditions (up to 1.1^{o}C warmer and up to 6% drier) expected around 2030 simulation studies show that in the Wimmera Mallee region yield losses can be offset through improved residue management and longer fallows.
- Under the same set of climate changes, but with no change in management, simulated median yields may be 15% lower than present long term yields. By changing current management practices to include longer fallows these losses can be ameliorated (i.e. only 6% lower). Your management can have a positive impact.
- Local crop management adaptations are likely to play a significant role in maintaining or increasing current productivity under variable and changing climate conditions.
- Climate variability and change are likely to continue to have different impacts in different regions and will require locally specific adaptation strategies.

Background

There is now firm evidence that the global climate has changed over the past century and will continue to change throughout the 21st century in response to continued growth in global greenhouse gas emissions (IPCC, 2007). There is growing evidence that current changes in climate are linked to both human activities and natural variability (CSIRO, 2007; IPCC, 2007) and that current patterns of change in Australia (particularly temperature but also rainfall) are consistent with those projected (Cai and Cowen, 2007; Timbal *et al*., 2006). History has demonstrated that natural resource based industries, such as agriculture, are particularly sensitive to climate with yields highly responsive to climate variations. For this reason a strong incentive exists to enhance the adaptive capacity of agricultural systems in order to deal with further changes expected as a result of human-induced climate change.

Our current farming environment is complex, being already characterised by market risk and variation in resource conditions and technologies. Climate change will further add to this complexity. However, there are many potential incremental adaptation options available to offset projected impacts (Howden *et al*., 2007). These incremental adaptation options often involve modification of current practises to offset risk associated with climate variability (Howden *et al*., 2007). Implementation of these options is likely to have substantial benefits under moderate climate change for some cropping systems (Howden and Crimp, 2005; Howden *et al.* 2004). However, there are limits to the effectiveness of incremental changes under more severe climate changes (Easterling *et al.*, 2007; Howden *et al*. 2007). Hence, more systemic changes in resource allocation need to be considered, such as targeted diversification of production systems and livelihoods.

Understanding which adaptation options to pursue in response to climate change remains a difficult and problematic exercise. This is largely due to the uncertainty associated with regional projections of climate change as well as the limited scope (i.e. largely simulation studies) for validating the effectiveness of adaptation. This paper presents two approaches that examine regional sensitivities to climate change and explore the effectiveness of a number of on-farm adaptation options. Both approaches have been applied in the Wimmera Mallee region.

Regional sensitivity

The first approach examines the sensitivity of a wheat-growing enterprise to a range of temperature, rainfall and CO_2 changes, using the APSIM cropping systems modelling framework and builds on a previously well tested methodology established earlier (Howden *et al*., 1999; Howden and Crimp, 2005; Howden and Jones 2001, 2004). In this approach the value of adaptation was examined by comparing likely impacts on yields for simulations with (1) no change in current planting window but planting different varieties and (2) variation of the planting window and varieties in response to increasing minimum temperatures.

Effectiveness of on-farm adaptation

In the second approach a distinct series of climate projections (‘low’, ‘medium’ and ‘high’) were linked to the APSIM modelling framework to assess the likely impacts of climate change on a range of crops and the effectiveness of a number of adaptation options. Five farming systems in the Wimmera Mallee were assessed, ranging from cropping to mixed cropping and grazing enterprises. A series of interviews were undertaken with farmers in order to accurately represent environmental conditions (e.g. soils) and the management undertaken on each farm. The interviews also explored what each farmer considered to be practical adaptation options to offset climate change. A subset of adaptation options identified by each farmer was tested on each of the five farms. The participatory research approach employed in this case recognised that much of the knowledge resides with the producers and that the most appropriate and practical adaptation options are likely to be identified through this approach.

Methods

Regional sensitivity analysis

In the first approach the APSIM modelling framework was implemented at a single location for a continuous wheat farming system on Mallee sandy clay loam soils. The climate change envelope in this sensitivity study included temperature increase of up to 4°C above current temperatures (0, 1, 2, 3, and 4°C) and +20% to -30% change in rainfall (-30, -20, -10, 0, 10, and 20%), for a series of different CO_2 concentrations, including 350, 450, 550, 650 and 750 ppm (parts of substance per million parts of sample).

To conduct the simulations described above a daily climate record was extracted from the SILO climate archive (a database managed and operated by the Queensland’s Climate Change Centre of Excellence http://www.nrw.qld.gov.au/silo/) for the period 1957 to 2006. Scenarios were constructed by scaling the daily maximum and minimum temperatures and daily rainfall based on the projections above, with no changes made to rainfall variability- only the amount of rainfall on a particular day. The crop simulations were set up in such a way that the soil water balance was maintained between crops, but soil N and organic matter were reset at sowing. This was necessary so that starting conditions reflected the ‘average’ district conditions to remove any effects of climate-change induced rundown of soil carbon. Sowing occurred in a window from 1 May to 30 June each year conditional on receipt of 15 mm of rain over three days. The seeds were sown at a density of 100 plants m^2 at a depth of 50 mm with 120 kg N ha^{-1} of fertiliser (NO_3-N) at the start and an additional 30 kg N ha^{-1} at three to five weeks after sowing, depending on rate of growth. This level of nitrogen fertiliser is likely to be more than is current practice in this region but was adopted so that the results are not confounded by nitrogen limitations. The impacts of important factors such as frost damage, pests, weeds and diseases were not modelled. Hence, the yields presented here will be higher than those actually achieved in this region.

The impact of modifying planting windows and varieties in response to warming was also considered. Planting windows were expanded in response to regional warming to allow earlier sowing opportunities to occur (Howden *et al.,* 2001). For currently used and shorter season varieties the planting window was opened on the 21 April, 11 April, 2 April and 28 March for a 1 ^oC, 2 ^oC, 3 ^oC and 4 ^oC warming respectively. For slow season varieties the window was opened on 19April, 4 April, 29 March and 22 March for a 1 ^oC, 2 ^oC, 3 ^oC and 4 ^oC warming respectively.

On-Farm adaptation analysis

Future climate scenarios for use in climate change impacts and adaptation analyses can be derived in many different ways. Each of these has its own set of issues (see IPCC 2001, 2007a for discussion). In this approach historical daily climate files were modified for a range of sites in the Wimmera Mallee based on patterns of change from the Hadley Centre (HadCM3) and CSIRO (MARK3) climate models (Figure 1). The patterns of change from each model are dependent on the extent of future global warming and in this approach a ‘low’, ‘mid’ and ‘high’ scenario of global warming was examined in order to sample across the range of future climate uncertainty (Figure 2).

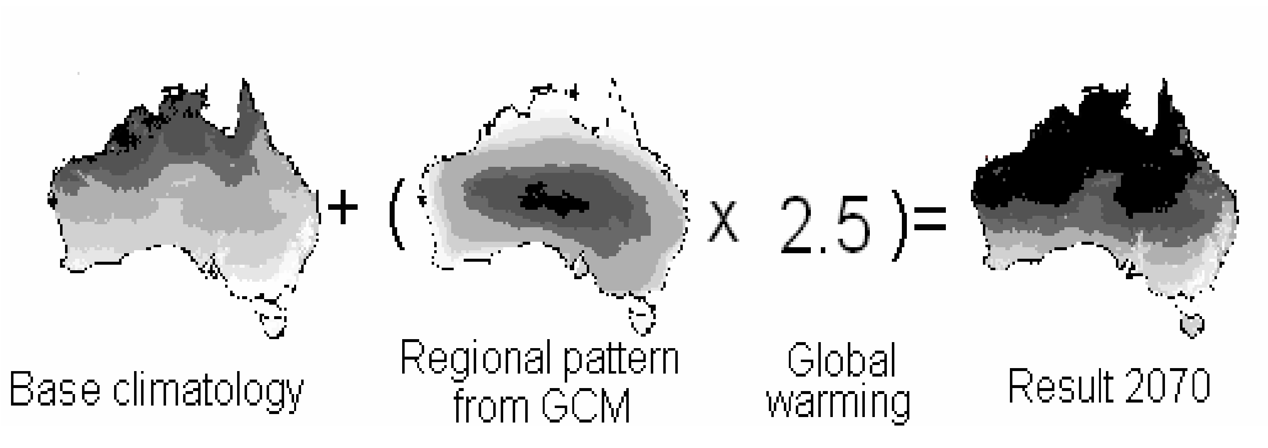

***Figure 1**: Schematic representation of the method employed to generate regional climate change projections (maps are indicative only). The global warming value of 2.5 represents the best estimate of warming for the 2070 period based on a mid range emission scenario. (modified from Whetton et al., 2001).*

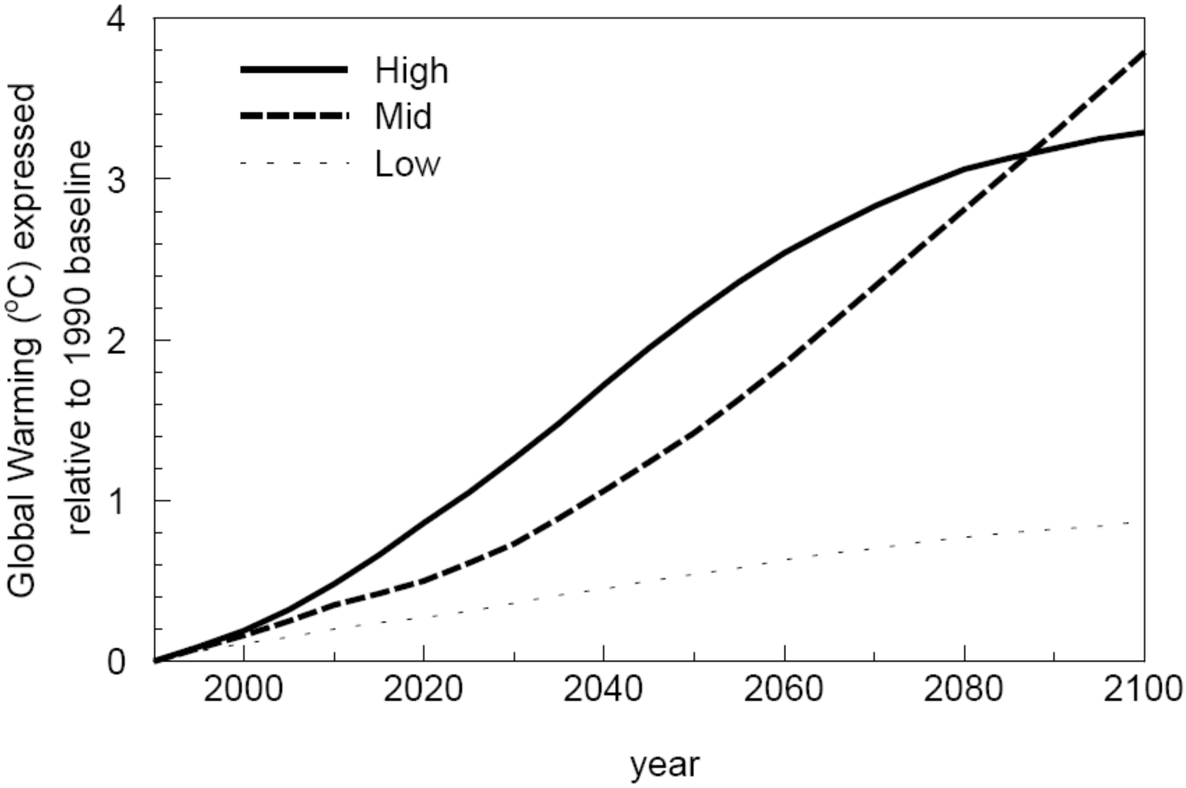

Figure 2*: Annual global warming values for the 'high', 'low' and 'mid' scenarios relative to 1990 (after IPCC 2001).*

As with the sensitivity analysis, crop simulations were undertaken using the APSIM model, although in this case more extensive testing was undertaken in order to accurately reflect both environmental conditions and current management for a number of cropping and mixed cropping and grazing farms in the Wimmera Mallee. Model considerations such as soil water balance, soil N and organic matter were determined on a site-by-site basis based on observational data and expert farmer knowledge (Crimp *et al*., 2007). Once initialised these parameters were not reset annually in order to ensure that a more realistic reflection of soil and soil water dynamics was attained over the simulation period (1957 to 2006). Sowing windows varied across sites with planting conditional on receipt of sufficient planting rains (i.e. between 15 and 25 mm of rain over a three day period depending on farm). Seeding rates and fertiliser management were determined at each site based on information provided by the farmer. Crop simulations were benchmarked against observed yield data for the period 1997 to 2005 in order to ensure accurate representation at each site. As with the sensitivity analysis important factors such as frost damage, pests, weeds and diseases were not modelled.

Farmers were asked to identify a range of adaptation options they would consider implementing in order to reduce possible negative impacts on crop yields. A range of both tactical and strategic responses were identified (Table 1) and a subset of four tactical adaptation options were assessed at each site. These included:

- increasing fallow or pasture;
- reducing planting density;
- selecting shorter season crops; and
- increasing residue retention.

Table 1: *Adaptation options identified by farmers in response to climate change risk.*

Tactical responses to climate change	Strategic responses to climate change
• Reduce the proportion of higher risk crops grown e.g. legumes	• Increase the size of the property including sandier soils.
• Reduce the amount of canola grown, although be prepared to be more opportunistic.	• Begin considering buying land in other areas that are more suited to cropping in the future.
• Fallow on a regular basis on heavier soils (crop less). A crop a greater proportion of the lighter soils on a more regular basis to compensate for smaller rainfall events.	• Begin to alter the cropping and livestock mix on the farm. (Note: some farmers indicated increasing the mix of cropping and livestock whereas others suggested moving from cropping to a more livestock orientated enterprise
• Select for shorter season varieties and more heat tolerant crops in springtime.	• Move towards lower input farming lower risk farming methods. This may result in lower year-to-year gross profit but longer-term profitability may be higher as conditions become drier and warmer.
• Lower stocking rates and retain more stubble to conserve soil moisture.	• Sell out or retire.
• Increase the diversity of crops grown on the farm.	• Buy light soil types
• Only grow legumes and canola on soils that have been long fallowed.	• Diversify into more off farm income sources e.g. feed lots for sheep/cattle
• Increase the length of fallow and proportion of the property fallowed.	• Look more into zero till by retaining all stubble and even look at biological farming practices.
• Sowing a larger percentage of the crop on paddocks that have been long fallowed.	• Increase involvement in field trails that examine the use of varieties better suited to future climate conditions.
• Consider growing more fodder crops and move out of wheat cropping.	• Improve marketing to increase cash returns, consider less weather dependent business investments.
• Reduce the level of cultivation in order to minimise soil disturbance e.g. greater use of minimum till.	
• Increase row spacing's and density of plantings.	

Results

Sensitivity analysis

Through the sensitivity approach the response of wheat to varying rainfall, temperature and CO_2 was assessed. In the discussion that follows we examine the possible wheat yield responses at 550 ppm for a range of temperature and rainfall changes.

An increase in CO_2 of up to 550 ppm alone (i.e. 0°C and 0% rainfall change scenario) resulted in a 32% increase in potential yields if planting windows were modified or a 28% increase in potential yields if no change in planting window occurred (Figure 3a,b). The yield response increased with increasing rainfall and moderate increases in temperature up to 1.5^{o}C if the planting window was modified (Figure 3a). However when no change in planting window occurred yield benefits from increasing rainfall were offset by any temperature increase (Figure 3b). This highlights the value of adaptive management whereby modification of the planting window in response to simulated warming of up to 1.5^{o}C resulted in an additional 15% yield benefit (Figure 3a, b).

In the modified planting window case the maximum yield response (98%) was achieved at the +20% rainfall and 1°C warming whilst the lowest yield response (-72%) occurred under the –30% rainfall and 4°C warming scenario. In the case where the planting window remained unchanged the maximum yield response (91%) was achieved at the +20% rainfall and no warming scenario whilst the lowest yield response (-77%) occurred under the –30% rainfall and 4°C warming scenario.

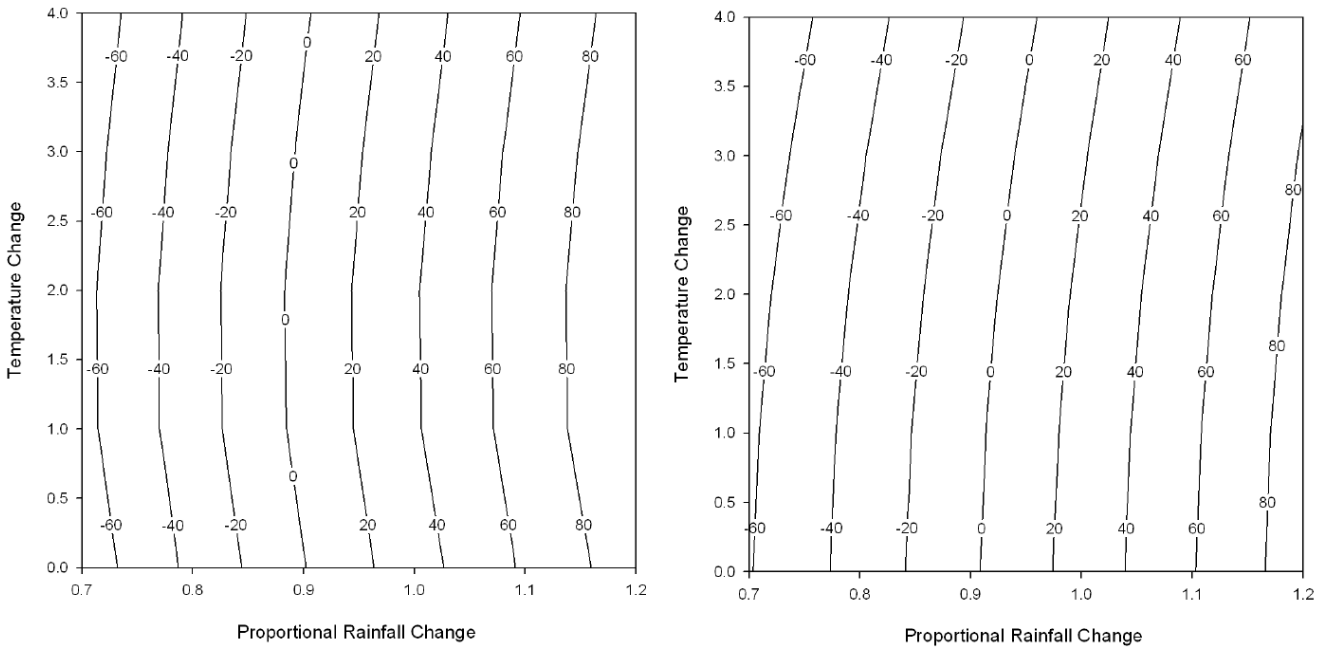

***Figure 3**: Birchip – Yield response (% change from baseline) to 550ppm CO_2 and a range of climate change scenarios with **(a)** modified planting windows and **(b)** no change in current planting window.*

Based on the CSIRO 2007 best estimate of climate change in this region by 2050 (i.e. 550 ppm, 2 to 2.5°C and -5 to -10% rainfall change), wheat yields may increase between 5% to 22% if planting windows are modified to account for rising temperatures. However if no change in planting windows occurs then yields changes of between -10 to 6% may occur (Figure 3b).

Similar analysis have been undertaken in the Mingenew-Irwin (WA) and Brigalow Jimbour regions (QLD) and are examined as part of final report to be submitted to the Australian Greenhouse Office and the Birchip Cropping Group.

Farm-based analysis

In the discussion that follows we examine the impacts of a ‘mid’ range global warming of only three different farming systems. The projected change is driven by the patterns of change from the HadCM3 climate model for 2030. We examine the likely impacts on wheat production for this particular climate change scenario and the value particular adaptation options have in offsetting this impact.

Under the ‘mid’ range global warming scenario local Birchip seasonal temperatures are projected to increase between 0.6 and 1.1°C and annual rainfall is projected to decline by four to six percent depending on farm location compared to the 1990 historical baseline. Ambient CO_2 concentrations of approximately 451 ppm are associated with this ‘mid’ range global warming scenario and have been considered in the crop simulations to account for likely reductions in crop transpiration efficiency and improved radiation use efficiency under higher CO_2 levels (i.e. the CO_2 fertilisation effect).

In the case of the first farming system (a wheat-fallow system) the mid-range 2030 climate change projections resulted in a 15% decline in median wheat yield if ‘no change’ in on-farm management occurred (i.e. a change from 3200 kg/ha to 2700 kg/ha) (Figure 4). Reducing planting densities (i.e. ‘Density’), increasing fallow (i.e. ‘Fallow’), increasing residue retention (i.e. ‘Residue’) or choosing shorter season varieties (i.e. ‘Variety’) resulted in only small offsets in yield loss, with an increase in the fallows resulting in only a six percent decline in median yields (Figure 4). On all three farms increased yield variability occurred as a result of climate change. This is consistent with recent finds from the IPCC Fourth Assessment Report (IPCC, 2007b). This is clearly demonstrated in the series of simulation experiments, with future yield ranges greater than present (Figures 4 to 6).

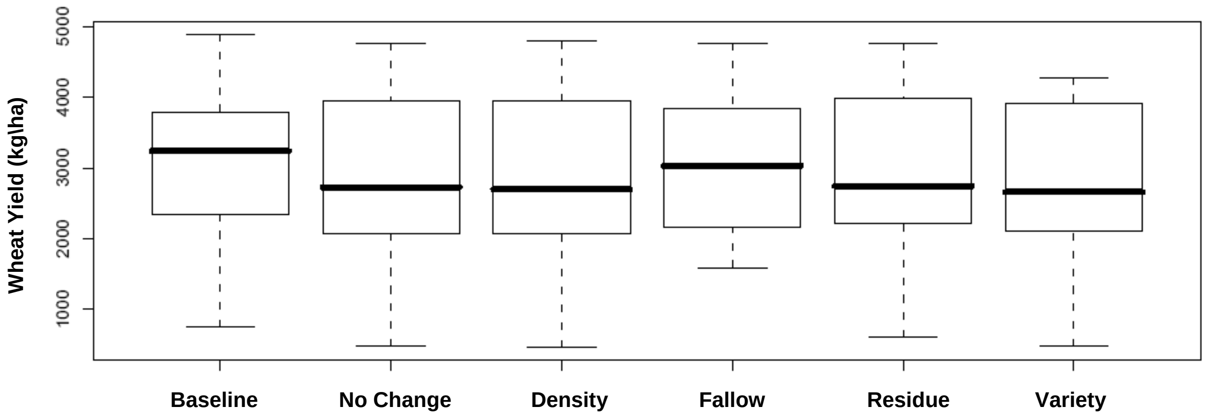

***Figure 4**: Birchip – Simulated wheat yields (kg/ha) for a wheat/fallow farming system under current climate conditions (baseline- 1957 to 2006) compared with simulated wheat yields under warmer and drier conditions under different management options. These include no change in current management ‘No Change’, reduced planting density ‘Density’, increasing fallow/pasture ‘Fallow’, increasing residue retention ‘Residue’ and choosing shorter season varieties ‘Variety’. The lower and upper edges of the box represent the 25^{th} and 75^{th} percentile yield values, the black line represents the 50^{th} percentile yield and the upper and lower whiskers represent the 1 and 100 percentile yield values.*

In the case of a mixed cropping and grazing system the mid-range climate change projections resulted in an 11% decline in median wheat yield if no changes were made to current management (i.e. from 3100 kg/ha to 2770 kg/ha) (Figure 5). By increasing residue retention (in an effort to reduce soil evaporation) to conserve moisture simulated yield losses were offset to only five percent lower than present. Increasing the amount of residue retained served to enhance yield performance in poorer years with the 25^{th} percentile simulated yields 50% higher under this management adaptation than present (i.e. 1780 kg/ha versus 1160kg/ha) (Figure 5).

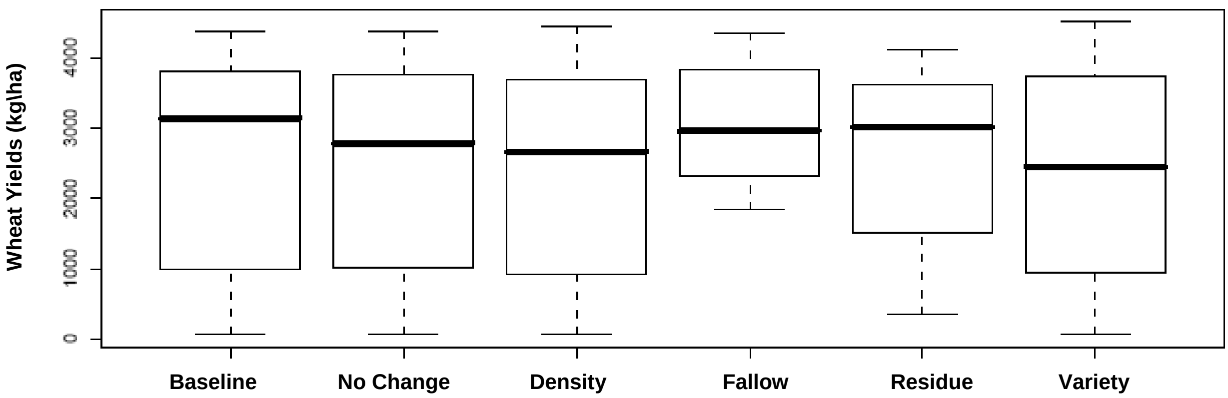

***Figure 5**: As in figure 4 but for a mixed cropping and grazing system.*

In a mixed cropping system the mid-range climate change projections resulted in a 15% decline in simulated yields if no changes in farm management were implemented. In this mixed cropping system the introduction of a fallow greatly improved the median wheat yields with a 30% increase in median yields above present (i.e. 2100 kg/ha to 2800 kg/ha).

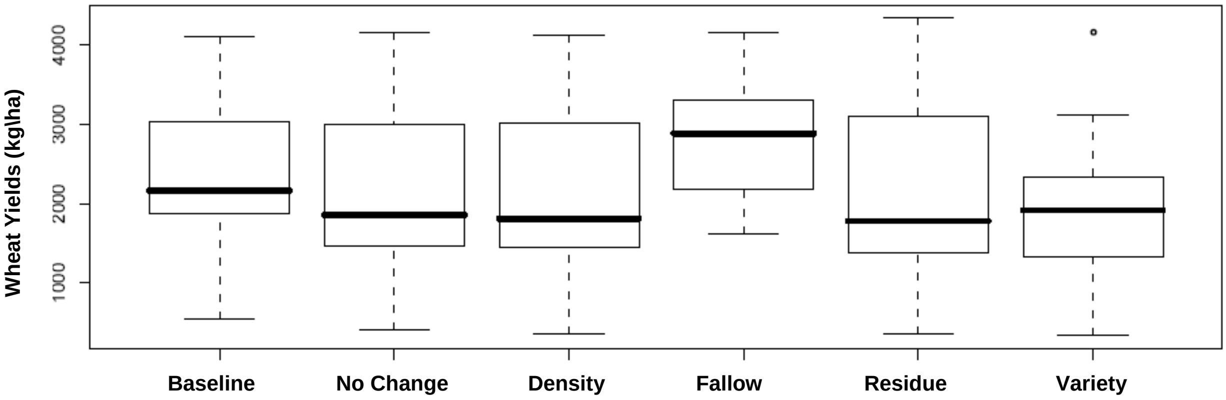

Figure 6*: As in figure 4 but for a mixed cropping system.*

Conclusions

Adaptation to both climate variability and climate change has already become a feature of agricultural production, especially in Australia. The prospect of adapting to significant climate change remains challenging, with the uncertainty of the extent of this change a major limiting factor.

In this paper we have presented two approaches by which to begin to address some of the inherent uncertainties. In the first approach the sensitivity of a simplified farming system to a range of climate change scenarios was examined. This approach allows a rapid assessment of regional vulnerability to climate change by allowing rapid evaluation of a range of climate changes to average yields.

In the second approach the impact of climate change projections on specific farming systems was examined for three farming systems in the Wimmera Mallee region. In this approach a number of farm level adaptation strategies for adapting to climate change were considered. This approach is effective at highlighting adaptation options that hold promise for dealing with future climate conditions but also those that give little benefit under the climate changes explored here.

In the final report to be submitted to the Australian Greenhouse Office and the Birchip Cropping Group both these approaches will be explored in more detail for the Wimmera Mallee, Jimbour Flood Plains and Mingenew-Irwin regions. Additional sensitivity analyses will be presented for the Jimbour Flood Plains and Mingenew-Irwin regions as well as an examination of value of on-farm adaptation options for a range of other crops grown in each of the three study regions.

There is a particular need to expand this type of approach that engages with farmers in a structured way to assess adaptation options. This allows a focus on the acceptability of adaptation options in terms of factors important to farmers and their perceptions of synergies and barriers (Howden *et al*., 2007).

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