

# Different response of soil and crop sequences to climate change in Western Australian mixed farm systems

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## Abstract

Western Australia is a major producer and exporter of crops and much of the production comes from mixed crop-livestock farms. Climate drives the productivity and profitability of these farms. Therefore, the effects of likely climate change on farm performance need to be understood. Here, the effects of climate change at 2030 were evaluated compared to a baseline period (1980-1999) on mixed farming systems for different soil types and rotation systems using the coupled APSIM and GRAZPLAN biophysical simulation models. Different crops' yields under historical and projected climates were assessed using current technology and management practices, including interactions with livestock. Representative mixed-farm systems were selected along a climate transect. Compared to the baseline, in 2030 crop yields had different responses to changes in climate in soil x current rotations, except for lupins. Under the hotter and drier potential climate of 2030, the greatest positive effect on wheat and barley yield was 20% (Katanning, Shallow sandy duplex, rotation: AAWC) and 37% (Cunderdin, Deep loamy duplex, rotation: WPWCB), while there was no increase projected for canola and lupin. The greatest decline of wheat and barley yield was 20% (Mullewa, Coloured sands, rotation: WLWC) and 16% (Cunderdin, Shallow sandy duplex, rotation: AAWCB, Katanning, Grey sandy duplex, rotation: AAB). Overall, current long term average productivity of rotation systems × soil type may change in near future depending on degree of changes in climate, suggesting requirement for optimizing current rotation systems to obtain maximised production and profitability.

## Key words

Climate change impact, modelling, agricultural system, cropping

## Introduction

Climate change predictions suggest that the scale and rate of change driven by increases in concentration of greenhouse gases in the atmosphere is unprecedented in human history, and will significantly – and in many cases dramatically – alter the accessibility and quality of natural resources (IPCC, 2014). Changes in key climatic variables such as temperature, rainfall, and atmospheric CO<sub>2</sub> will act to push agro-ecosystems towards their thresholds of change, which potentially can threaten the future of agricultural industries and communities dependent on them. In this paper we explore the impact of changing climate on the agricultural productivity of mixed farming enterprises in Western Australia (WA). Western Australia is a major contributor to the Australian agri-food sector and economy with mixed farming enterprises practiced over diverse climates and soil types. In the 2012/13 financial year the Western Australian cropping industries exported a total of \$3.9 billion with \$2.2 billion of wheat exports (8.5 million tonne) (Department of Agriculture and Food, 2013). A wide range of soils occurs in south-western Australia. These soils, including those at the representative sites, are of varying depth with the majority having sandy topsoils with low clay content and organic matter and are often constrained by acidity (Anderson and Garlinge, 2000; Moore, 2001). Agriculture in WA is possible because of the relatively reliable winter rainfall under the region's Mediterranean climate. This region has temporal variability of rainfall and evidence of an overall decline in winter rainfall over the past century. The effects of climate change at 2030 were evaluated compared to a baseline period (1980-1999) on mixed farming systems for different soil types and rotation systems using the coupled cropping and animal enterprises. This work presents modelling of the complex interactions among climate, soil, crops, pasture, and animal within a whole farm system. This modelling of the potential impact of climate change is a first step toward designing adaptation strategies.

## Methods

We selected four representative mixed farming systems across a climate gradient of 241-369 mm growing season rainfall (Apr-Oct) using the base period 1980-1999. These sites range from the dryer inner edge of the grains belt to the medium-high rainfall zone and represent complex agro-ecosystems with different

soils, farm and livestock management, input intensity and scale of operation. Facilitated workshops were used to select the sites and characteristics of representative farms. Stakeholders at the workshops included farmers, representative of farmer groups, consultants, and research and extension officers of Department of Agriculture and Food Western Australia. At these workshops we agreed on soil type, landuse, pasture, cropping and livestock. This was complemented by available literature along with published and unpublished surveys (Co-operative Bulk Handling, 2013 unpublished; ABARES, 2014).

Coupled Model Intercomparison Project Phase 5 (CMIP5) models were used for likely future climate of “Hot and dry”, “Hot and moderate changes in rainfall”, and “Warm with least changes in rainfall” (Table 1). Two “representative concentration pathways” RCP 4.5 and RCP 8.5 scenarios (IPCC, 2013) were applied with high and low sensitivity that allowed us to sample across the more likely range of possible future climates in the focus year of 2030 using three global climate models (GCM): HADGEM2-AO, GFDL CM3, and MIROC5. These GCMs were statistically downscaled using the quantile matching method which produces daily weather data sequences. Combinations of RCP 8.5 x high sensitivity x GFDL CM3 considered as hot and dry (HD), CP 8.5 x high sensitivity x MIROC5 GCM, hot and increased rainfall (HMCR), and CP 4.5 x low sensitivity x HADGEM2-AO, considered as potential climate of warm with modest changes in rainfall (WLCR) (Table 1). Atmospheric CO<sub>2</sub> concentrations of 435 ppm for 2030 under the RCP 4.5 and 449 ppm under RCP 8.5 scenarios were assumed. For the baseline, monthly atmospheric CO<sub>2</sub> concentration measured in Cape Grim station was used for period of 1980-1999 which ranged between 335.7 ppm and 366.5 ppm.

Each representative site had several soil types and rotation systems (Table 2). A representative range of soils for each site was characterized using APSOIL database. Most soils had topsoils that are relatively low in clay and soil organic matter and were frequently constrained by acidity. Consequently, the fertility and water holding capacity is low. The main crops of wheat, barley, canola, lupin, and field pea were simulated. Field peas were used in the model as a green manure. Pasture species identified are annual ryegrass, subterranean clover, and biserrula. The baseline sowing date window and reference wheat cultivar for each site were selected based on local conditions via producer workshops and the Planfarm Bankwest Benchmarks (Anonymous, 2014). Sowing for all crops was simulated when 5-day (Cunderdin and Katanning) or 3-day (Mullewa & Merredin) total rainfall exceeded 10 mm. The only reset in the modelling was for biomass and humus at the end of rotation. Soil organic matter (SOM) of pastures was reset at the first day of year. To evaluate the effect of rotations there was no resetting of soil water or N. Biophysical simulation models of integrated crop-livestock systems were constructed by linking the APSIM soil water, soil nutrient cycling, crop and surface residue simulation models to the GRAZPLAN pasture and ruminant simulation models (Donnelly et al., 2002) using the AusFarm modelling software (version 1.4.7). Here, additional functions were applied to account for frost and heat stress on crops further to APSIM’s current formulation. Management systems were described using flexible rules that allocated land to the different crop-pasture sequences and then managed the sowing and removal of the various crop and forage species, nitrogen fertilizer (N) applications, the annual cycle of sheep reproduction, buy and sale, supplementary feeding and grazing management. Simulated crop yields were validated through producer workshops and with regional database of Co-operative Bulk Handling (CBH) (Anonymous, 2014 unpublished) for a period 1996-2013 as the best proxy yield data available.

## Results

In the hotter and drier HD future temperature was projected to increase between 1.0 °C and 1.4 °C across the transect with smallest and greatest increase at Katanning and Mullewa, respectively. Under the warm with modest change in rainfall WLCR future the temperature increase across sites was between 0.5 °C and 0.7 °C. Annual rainfall declined in all sites and all future climates but there were differences in seasonality. There was an increase in spring and late-summer (February) rainfall projected at most sites, however, it was accompanied with increased temperature.

When compared to the 1990 baseline (that is the period from 1980-1999), projected crop yields in 2030 declined for most of the combinations of crop × site × future climates, with less decline in the WLCR future than the HD future (Table 2, Fig 1). The changes in crop yields differed according to crop, rotation by soil combination and future climate. Crop yields of lupin declined in all instances and canola yields in all but one instance. The declines were by up to 27% for lupin in the HD future and 19% in the WLCR future, and by up to 24% for canola in the HD future and 18% in the WLCR future. Wheat yields declined more often than

not (12 out of 17 situations in both the HD and WLCR futures) with most of declines being more than 5%. The declines in wheat yield were up to -16% in the HD future and -11% in the WLCR future (both Mullewa), but the increases were up to 12% and 20% for HD and WLCR, respectively. Barley yields in future climates were almost equally likely to increase as they were to decrease. When barley yields were simulated to increase, the barley typically followed a canola crop in the rotation sequence.

**Table 1. Projected future climates**

Likely future climate	Abbreviation	Scenario	Sensitivity	GCM
Hot and dry	HD	RCP 8.5	High	GFDL CM3
Hot and moderate changes in rainfall	HMCRC	RCP 8.5	High	MIROC5
Warm with least changes in rainfall	WLCR	RCP 4.5	Low	HADGEM2-AO

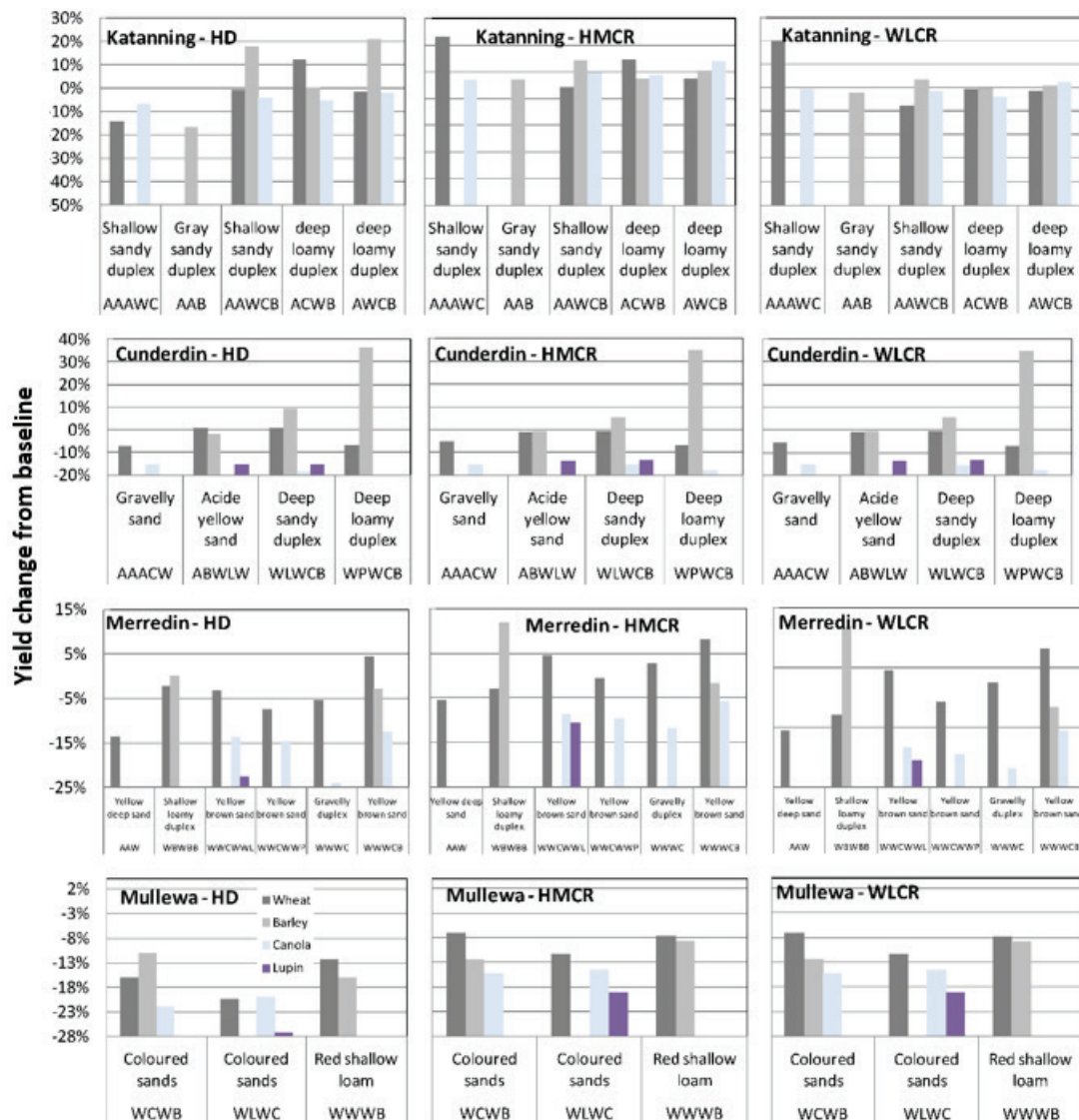
**Table 2. Relative change (%) in crop yields in 2030 of each crop x soil type x rotation for HD and WLCR potential future climates compared to the baseline. A: annual pasture, W: wheat, C: canola, B: barley.**

<u>Katanning</u>	Soil	HD				WMCR			
		Wheat	Barley	Canola	Lupin	Wheat	Barley	Canola	Lupin
AAAWC	Shallow sandy duplex	-14%		-7%		20%		-1%	
AAB	Grey sandy duplex		-16%				-2%		
AAWCB	Shallow sandy duplex	0%	18%	-4%		-8%	3%	-1%	
ACWB	Deep loamy duplex	12%	0%	-5%		0%	0%	-4%	
AWCB	Deep loamy duplex	-1%	21%	-2%		-1%	1%	2%	
<u>Cunderdin</u>									
AAACW	Gravelly sand	-7%		-16%		-5%		-15%	
ABWLW	Acide yellow sand	1%	-2%		-15%	-1%	0%		-14%
WLWCB	Deep sandy duplex	1%	9%	-18%	-15%	-1%	6%	-15%	-13%
WPWCB	Deep loamy duplex	-7%	37%	-20%		-7%	35%	-18%	
<u>Merredin</u>									
AAW	Yellow deep sand	-13%				-6%			
WBWBB	Shallow loamy duplex	-2%	0%			-3%	12%		
WWCWWL	Yellow brown sand	-3%		-14%	-22%	5%		-8%	-11%
WWCWWP	Yellow brown sand	-7%		-15%		-1%		-10%	
WWWC	Gravelly duplex	-5%		-24%		3%		-12%	
WWWCB	Yellow brown sand	5%	-3%	-12%		8%	-2%	-6%	
<u>Mullewa</u>									
WCWB	Coloured sands	-16%	-11%	-22%		-7%	-12%	-15%	
WLWC	Coloured sands	-20%		-20%	-27%	-11%		-14%	-19%
WWWB	Red shallow loam	-12%	-16%			-8%	-9%		

Modelling results indicated a 12% increase in wheat yield at Katanning (HD). The current management includes wheat grazing in AAAWC, and AAWCB rotations on low quality shallow sandy duplex soils which resulted in simulations of late flowering and low yields. Wheat yield is very sensitive to the timing of flowering, a common rule of thumb is a 5% reduction in yield for every week that flowering is delayed. This reduction will be exacerbated with added damage functions for heat waves. A major impact of a hotter climate will be earlier flowering. The low water holding capacity of these soils rather than insufficient nitrogen fertilizer were simulated to be the causal factor in low yields as indicated by up to 266% higher whole year soil water stress of photosynthesis (total daily water uptake by roots/soil water demand of plant) in shallow sandy duplex soil compared to the other soils. Nitrogen stress for photosynthesis was not significantly different among rotation and soils. The future climates altered the amounts of water stress. For example, at Katanning, soil water stress for wheat changed differently among soils and rotations under different scenarios of climate change. The rate of change of long term average soil water stress of wheat in the ACWB rotation compared to the historic baseline increased by up to 87% under HD future and by up to 25% in the WLCR future. However, for wheat in the AWCB rotation (deep loamy duplex) soil water stress decreased by -31% and -38% under HD and WLCR futures respectively.

## Conclusion

There was generally a negative effect of changes in climate on crop yields across soils and current rotation systems while some positive effects were also realized. Water and nitrogen stresses varied among soil × crops × rotation systems × potential climate in comparison to the historical climate. Long term average productivity of rotation systems × soil type may change in near future depending on degree of changes in climate, suggesting requirement for optimizing sequencing systems to obtain maximised production and profitability.



**Figure 1. Relative change in crop yields under potential climates compared to the baseline.**

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