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Impact of climate changes on existing crop-livestock farming systems

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ABSTRACT

The state of Western Australia is a major producer and exporter of crops and livestock. Mixed farming systems are typical agricultural enterprises in the Western Australian wheatbelt where climate drives the productivity and profitability of these farms and therefore the effects of likely climate change on their performance need to be understood. Here the effects of climate change projected at 2030 were evaluated compared to a baseline period (1980–1999) on mixed farming systems at paddock, enterprise and whole farm scales using the coupled APSIM and GRAZPLAN biophysical simulation models. The yield of different crops, livestock production and gross margins were assessed under current and projected climates using current farming technology and management practices. Representative mixed-farm systems were selected along a climate transect. Modelling analysis suggests that current production levels and gross margins of mixed farm systems in Western Australia will not be sustained in 2030 climate conditions except in areas of moderately high-rainfall. Whole farm gross margin declined at all site × potential climate scenarios between 1% and 22% except in moderately high rainfall where gross margin increased by up to 4% under a 'hot and moderate change in rainfall' climate. Projected crop yields declined for most of the crop × site × potential climate combinations, with greatest declines under a hot and dry climate (at driest margin of transect) in which wheat, barley, canola, and lupin yield declined up to 16%, 15%, 21%, and 27%, respectively. Increase in yield was predicted for wheat and barley at some of the site × potential climate s. Wheat yield increased only under moderately high rainfall region by 6% while barley increased by 1%. Simulated cropping gross margin was also shown to decline by between >1% and 23%, except for the moderately high-rainfall site where cropping gross margins were projected to increase by up to 3%. Changes in simulated livestock production were smaller and less variable than for crop production. The change in weight of livestock sold across sites × potential climate combinations ranged between −3% and +3%. Livestock gross margin varied between −11% and +6%. Modelling results indicated a greater fertilisation effect of the elevated CO_2 on pasture production than on crop yield and biomass particularly in drier sites. But however, this could not offset negative impact of climate change under hot potential climates. The main negative environmental impacts from the projected climate change were declines in annual net primary production (ANPP), ground cover and water use efficiency mostly at drier sites. Whole farm N_2O emission declined significantly for the majority of site × potential climate combinations, while smaller decreases in ruminant CH_4 emission were predicted. In 2030, returns from livestock enterprises are predicted to be smaller, but less variable than from cropping and with increasing probability of success in drier regions. Reduced variability in financial return is important from the perspective of whole farm risk management. Shifts in enterprise mix in dryland mixed-farming systems towards increased livestock may be a helpful strategy in adapting to climate change and managing the associated financial risks.

1. Introduction

Climate change projections 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 and rainfall will act to push agro-ecosystems towards their thresholds of change, in some cases threatening the future of agricultural industries and communities (Lenton, 2011; Wilbanks, 2003). Primary enterprises and industries, which include the sectors of agriculture, are highly vulnerable to climate change because of their dependency on climate-sensitive natural resources for their prosperity and sustainability (Zamani et al., 2006). Specifically, primary enterprises are expected to contend with more frequent climate crises, environmental degradation and even climate-related regulatory change (IPCC, 2007). Climate related stressors occur against an existing backdrop of conventional drivers

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including economic, biophysical, institutional, cultural and political pressures (Howden et al., 2007; Marshall et al., 2012).

There is a good deal of literature on the potential impacts of climate change on single agricultural enterprises (e.g. Cullen et al., 2009; Ghahramani et al., 2015 and Ludwig and Asseng, 2006 in Australia; Butterworth et al., 2009 in the UK; Ducharne et al., 2007 in France; Ko et al., 2012 in the USA). Multiple-enterprise farms are central to agriculture in much of the world Herrero et al. (2013) estimate that 69% of global milk production and 61% of ruminant meat production is sourced from crop-livestock farms. Despite their economic and social importance, and the likelihood that both climate change impacts and the options for adapting to changed climate will be different when multiple enterprises are present, studies considering climate change impacts on integrated crop-livestock systems are uncommon. The only two examples we have found are Rodriguez et al. (2014), who analysed mixed-farming systems in southern Queensland, and Rigolot et al. (2016), who examined the impact of climate change on smallholder crop-livestock systems in Burkina Faso.

Broadacre farming contributes approximately AU$33 billion (mean across the five years to 2011–12) to Australia's agricultural export earnings (ABARES, 2013) and provides a mean return of around AU$83,000 per farm (mean across the 10 years to 2011–12). Broadacre farming is strategically important to the Australian economy because it ensures a reliable domestic and international supply of grain and meat products. In southern Australia (including the wheat belt of Western Australia), broadacre farming can be characterised predominantly by mixed cropping and livestock systems that include diverse enterprises where wool and sheep meat production are integrated with cereal, pulse and oilseed crops and where pastures are incorporated into the cropping sequence (Kirkegaard et al., 2011).

Australia's primary industries have historically operated in a highly variable climate. This has posed significant challenges to production, requiring sound and responsive risk management practices. Climate change has, and will, introduce even greater challenges. This means that there is a need to assess the impact of climate change in order to explore vulnerabilities and opportunities for farmers to improve how they respond to climate variability.

Western Australia (WA), with about 4 million ha of wheat-growing farms, is a major contributor to the Australian agrifood sector and economy. 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) (The Department of Agriculture and Food WA, 2013). Pastures in WA have a major role in agricultural enterprises and contribute over $3 billion annually in Western Australia through animal production, improvements to crop rotations and conserved fodder (The Department of Agriculture and Food WA, 2014). Livestock is an important part of agriculture in WA. In 2011/12, the WA livestock industries contributed 26% of the state's agriculture, fisheries and forestry production, worth approximately $2 billion at the farm gate (Department of Agriculture and Food, 2012).

In addition to the practical importance of understanding climate change impacts in the region, WA mixed farming systems have features that make them useful as a case study contributing towards a wider understanding of climate change impacts on agriculture. First, there is clear evidence of an overall decline in winter rainfall in southern WA over past decades (Delworth and Zeng, 2014), so that the issue of changing climate is particularly salient to WA farmers. Second, and in contrast to the environments studied by Rodriguez et al. (2014) and Rigolot et al. (2016), the climate in WA is Mediterranean and its agriculture therefore relies heavily on winter rainfall. Third, and again in contrast with southern Queensland, mixed farming systems in WA are typically integrated in space (Bell and Moore, 2012); sequences of crops and pastures occupy the same land. Fourth, the WA wheatbelt has a high temporal variability of rainfall (Smith et al., 2000) that requires sound and responsive risk management practices. Fifth, WA can be a good place for examining impact of projected climate change scenarios on agriculture because main agricultural productions of WA i.e. wheat and livestock are for international export and thus can be assumed to be sensitive to global socioeconomic factors which are fed into AR5 emissions scenarios that we have used in here (Stocker et al., 2013).

In Australian crop-livestock systems, an emphasis on livestock is currently a less risky strategy compared to cropping for managing climate variability (Kingwell et al., 2013). Climate change has, and will, introduce even greater risk-related challenges. This means that there is a need to assess the impact of climate change in order to explore vulnerabilities and opportunities for farmers to improve how they respond to climate variability. Over the last 30 years crop yields in WA have increased by an average of 1.2% P.a., which has been related largely to the closing yield gap by improvement in agronomic technologies (Fischer et al., 2014). However, there is little prospect of increasing current crop yield with current technologies and in the near future (Fischer et al., 2014; Ghahramani et al., 2015). In Australian mixed farm systems, an emphasis on livestock is a less risky strategy compared to cropping for managing climate variability (Kingwell et al., 2013). From 1980 to 2000 there was a marked shift towards cropping on WA mixed farms (Bell and Moore, 2012) which appears to have been driven mainly by greater expected profitability of crops and by labour availability constraints associated with increasing farm sizes. Given that there is less prospect of further closing the yield gap for crops with current technologies and there are likely negative effects of changes in climate on cropping systems, we can hypothesize that livestock might be still a viable and lower risk enterprise under changed climate conditions. There is a capacity for greater livestock production even under projected climate changes (Ghahramani and Moore, 2015) and a predicted increase in global demand for meat (Godfray et al., 2010). Thus, livestock might be a favourable enterprise in the near future.

This paper identifies the likely effect of climate change projected for 2030 on current mixed farm systems of Western Australia across a climate transect in terms of impacts on production, gross margin, and environmental consequences. Here, impact of climate change evaluated for projected climate scenarios in 2030 relative to a historical baseline of 1980–1999. This work presents modelling the complex interactions among climate, soil, crops, pasture, and animal within a whole mixed farm system. Evaluating the impacts of climate change in this way is a necessary first step towards designing climate adaptation strategies through assessing options such as shifts towards more intensive livestock systems and dual-purpose cropping. We will address the effectiveness of climate adaptation options in subsequent papers.

2. Methods

Our modelling analysis was designed to investigate how specific farming systems which are representative of good present-day practice would respond to current and future climates. It therefore does not consider future improvements in plant or animal genetics (as in Moore and Ghahramani, 2013); nor does it incorporate any anticipated adaptations to changing climate. We carried out a “stationary” analysis (Moore and Ghahramani, 2013; Williams et al., 2015), in which trends in slowly-changing variables such as soil organic matter content and average prices were removed. Each year of a given simulation should therefore be considered as a realisation of the variable climate obtaining at a particular time (1990 in the historical simulations, 2030 in the future scenarios).

2.1. Study sites

We selected four representative mixed farming systems in Western Australia across a climate gradient of 241–369 mm growing season rainfall (April–October 1980–1999 means; Fig. 1a). These sites represent complex agro-ecosystems (Fig. 1b) with different soil, crop and livestock management, and different levels of input intensity. Selection of sites and identification of cropping and livestock management systems were performed through facilitated workshops with stakeholders