Agricultural Systems 164 (2018) 236–251

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Transformative and systemic climate change adaptations in mixed crop-livestock farming systems

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ARTICLE INFO

Keywords:
Climate change
Adaptation
Mitigation
Integration
Modelling
GHG
Land use change

ABSTRACT

Mixed crop-livestock farming systems provide food for more than half of the world's population. These agricultural systems are predicted to be vulnerable to climate change and therefore require transformative adaptations. In collaboration with farmers in the wheatbelt of Western Australia (WA), a range of systemic and transformative adaptation options, e.g. land use change, were designed for the modelled climate change projected to occur in 2030 (0.4–1.4° increase in mean temperature). The effectiveness of the adaptation options was evaluated using coupled crop and livestock biophysical models within an economic and environmental framework at both the enterprise and farm scales. The relative changes in economic return and environmental variables in 2030 are presented in comparison with a baseline period (1970–2010). The analysis was performed on representative farm systems across a rainfall transect. Under the impact of projected climate change, the economic returns of the current farms without adaptation declined by between 2 and 47%, with a few exceptions where profit increased by up to 4%. When the adaptations were applied for 2030, profit increased at the high rainfall site in the range between 78 and 81% through a 25% increase in the size of livestock enterprise and adjustment in sowing dates, but such profit increases were associated with 6–10% increase in greenhouse gas (GHG) emissions. At the medium rainfall site, a 100% increase in stocking rate resulted in 5% growth in profit but with a 61–71% increase in GHG emissions and the increased likelihood of soil degradation. At the relatively low rainfall site, a 75% increase in livestock when associated with changes in crop management resulted in greater profitability and a smaller risk of soil erosion. This research identified that a shift toward a greater livestock enterprises (stocking rate and pasture area) could be a profitable and low-risk approach and may have most relevance in years with extremely low rainfall. If transformative adaptations are adopted then there will be an increased requirement for an emissions control policy due to livestock GHG emissions, while there would be also need for soil conservation strategies to be implemented during dry periods. The adoption rate analysis with producers suggests there would be a greater adoption rate for less intensified adaptations even if they are transformative. Overall the current systems would be more resilient with the adaptations, but there may be challenges in terms of environmental sustainability and in particular with soil conservation.

1. Introduction

Mixed crop-livestock enterprises dominate agricultural systems in many parts of the world and provide food for more than half of the world's population (Herrero et al., 2010). In Australia, mixed crop-livestock farms are also major agricultural systems across low rainfall regions (Bell et al., 2014) and are important for their economic and social contribution to rural communities. The projected adverse impact of climate change might result in a significant decline in grain, wool, and meat productivity of Western Australian mixed-farming systems (Ghahramani and Moore, 2016), while adaptations which may offset this decline are a hypothesis worth testing. Australia's primary industries have always performed in a highly variable climate with significant related challenges, e.g. soil water management and soil erosion, and this has required innovative climate risk management practices to be developed. Climate change brings with it some new variations on these challenges not yet accounted for by Australian primary producers, e.g. greater frequency of years with extremely low rainfall (Crimp et al., 2016) and a decrease in water use efficiencies (Ghahramani et al., 2015). Previous research (e.g. Ghahramani and Moore, 2013, 2016;

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https://doi.org/10.1016/j.agsy.2018.04.011
Received 25 November 2017; Received in revised form 24 April 2018; Accepted 29 April 2018

Lobell et al., 2008; Lesk et al., 2016; Vermeulen et al., 2013) has suggested that incremental adaptation strategies may not be sufficient to offset the impact of climate change on agricultural productivity, thus requiring primary industries to adopt more systemic or transformative adaptations (Ghahramani and Moore, 2015). These include changes in the function or structure of current systems to sustain productivity and profitability under changing climate (Rickards and Howden, 2012; Marshall et al., 2016). There is a likelihood that climate change impacts and adaptations may be different in mixed systems from non-mixed systems due to a wider variety of enterprises being present. Currently, there is limited previous research on this topic (e.g. Rigolot et al., 2017 for Africa) that considers climate change impacts and adaptations on integrated crop-livestock systems while also considering economic and environmental health.

The interactions between crops and livestock can be managed to contribute to sustainable production and risk management, but there is a severe knowledge gap on these interactions under climate change (Thornton and Herrero, 2014). There is also a need for an analysis of the impact of localised climate change on agricultural systems for a better understanding of their possible evolution in an integrated framework. This integration should consider different dimensions of sustainability e.g. environment, economic (Thornton and Herrero, 2014; Thornton and Herrero, 2015).

Western Australia, with about 7 million ha of land used for grain production, is a major contributor to the Australian agrifood sector and, as a result, the Australian economy (The Department of Agriculture and Food, 2014 (ABARES, 2014)). Pastures in this state play a significant role in agricultural enterprises and contribute over $3 billion annually through animal production, improvements to crop rotations and conserved fodder (The Department of Agriculture and Food, 2014). In addition to the practical importance of understanding climate change effects in the region, Western Australian mixed farming systems have characteristics that make them useful as a case study for a wider understanding of the impact of climate change on agriculture (Ghahramani and Moore, 2016). There is clear evidence of an overall decline in winter rainfall and increased temperatures in southern regions of the state over past decades (CSIRO and Bureau of Meteorology, 2014; Delworth and Zeng, 2014), and the issue of changing rainfall is particularly salient and well known to farmers (discussed in stakeholder workshops and has been personally experienced by the second author). In addition, as most of the agricultural commodities produced in Western Australia, i.e. wheat, barley, canola, wool, and meat are for international export, we can, therefore, assume that their market is sensitive to global socioeconomic factors (Ghahramani and Moore, 2016) which are fed into AR5 emissions scenarios that have been used here (Stocker et al., 2013).

In the first of this series (Ghahramani and Moore, 2015), the impact of climate change in Western Australia mixed crop-livestock systems was evaluated. In this paper, the effectiveness of a range of systemic and transformative adaptation options have been identified and evaluated with producers and their advisors who were already familiar with climate-related issues, e.g. climate variability. This paper evaluates economic and environmental resilience and adaptive capacity of the current farms (Rivington et al., 2007) under climate change by application of adaptation options. All evaluations were reported for 2030, relative to a historical baseline of 1970–2010 (to be consistent with the 5th report of Intergovernmental Panel on Climate Change, i.e. Clarke et al., 2014) across a high to low rainfall climate transect. This paper considers the effectiveness of adaptation options at multiple level (enterprise and farm) and against various criteria (profit, risk, environmental impacts, and GHG emissions). This provides key insights into the challenges associated with managing land use change resulting from climate change while evaluating a range of systematic adaptation options in sustaining productivity and profitability under such changes.

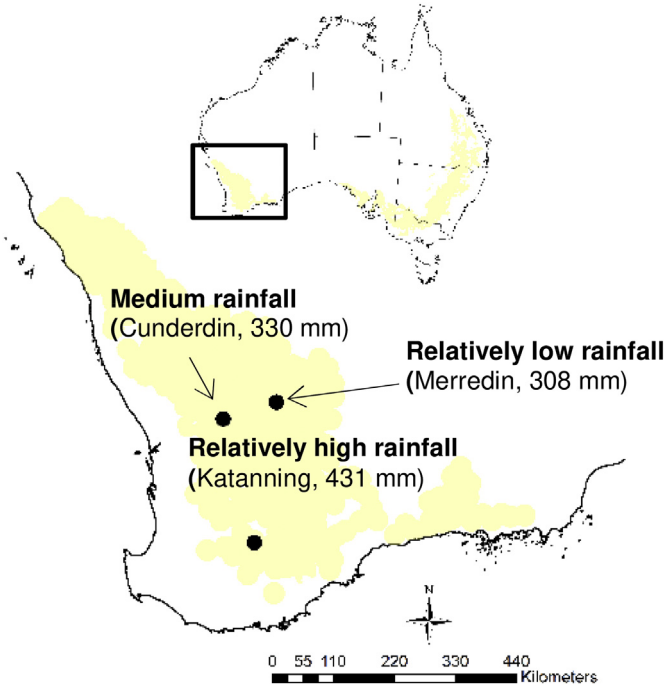

Fig. 1. Representative mixed farms. Numbers in brackets are average rainfall during 1970–2010.

2. Methods

2.1. Study sites

Three representative mixed farming systems were selected across a historical rainfall gradient of 308–431 mm (growing season rainfall during Apr-Oct, 1970–2010) (Fig. 1). Three sites were chosen to represent farming systems of relatively high rainfall (Katanning), medium rainfall (Cunderdin), and relatively low rainfall systems (Merredin). These sites represent complex agroecosystems, each with different soil, management, and input intensities (Table 1). These sites are those used in Ghahramani and Moore (2016) which were selected and identified through workshops with a range of related stakeholders including extension and research officers from Department of Agriculture and Food Western Australia, farmers, representatives of farmer groups, and consultants.

2.2. Modelling & representative farming systems

2.2.1. Modelling approach

Mixed crop-livestock farms are complex systems which include interactions between climate and weather, surface and sub-surface soil, vadose zone, crops, pasture, animal production and human management with economic components. The climate, through weather and the timing of weather patterns, is one of the main factors because rainfall and temperature drive the productivity, profitability and environmental health of the system. Integrated models of crop-livestock systems were constructed by linking the APSIM 7.7 soil water, soil nutrient cycling, crop and surface residue modelling components (Holzworth et al., 2014) to the GRAZPLAN pasture and ruminant simulation models (Donnelly et al., 2002; Moore et al., 1997) using the AusFarm modelling software (version 1.4.7). AusFarm is an agroecosystem modelling environment that couples APSIM and GRAZPLAN to model dynamic interactions between climate, soil, plants, and animals (Ghahramani and Moore, 2016).