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Climate change impacts and farm-level adaptation: Economic analysis of a mixed cropping–livestock system

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ABSTRACT

The effects of climate change on agricultural profitability depend not just on changes in production, but also on how farming systems are adapted to suit the new climatic conditions. We investigated the interaction between production changes, adaptation and farm profits for a mixed livestock–cropping farming system in the Western Australian Wheatbelt. Crop and pasture production was simulated for a range of plausible rainfall, temperature and CO_2 concentrations for 2030 and 2050. We incorporated the results of these simulations into a whole-farm bio-economic optimisation model. Across a range of climate scenarios, the impact on farm profit varied between −103% and +56% of current profitability in 2030, and −181% and +76% for 2050. In the majority of scenarios profitability decreased, and the magnitude of impacts in negative scenarios was greater than the upside in positive scenarios. Profit margins were much more sensitive to climate change than production levels (e.g., yields). Adaptive changes to farm production under extreme climate scenarios included reductions in crop inputs and animal numbers and, to a lesser extent, land-use change. The whole-farm benefits of these adaptations were up to $176,000/year, demonstrating that estimating the impact of climate change without allowing for adaptation can substantially inflate costs. However, even with adaptation, profit reductions under the more negative scenarios remained large. Nevertheless, except for the most extreme/adverse circumstances, relatively minor increases in yields or prices would be sufficient to counteract the financial impacts of climate change (although if these price and/or productivity increases would also have occurred without climate change then the actual cost of climate change may still be high).

1. Introduction

The effect that climate change has on the productivity and economic viability of agriculture will depend on how much it is possible to adapt to reduce the change's impact (Lobell, 2014). Therefore, estimates of the economic impact of climate change will likely be overstated if adaptation is not allowed for. Nonetheless, in many existing projections of climate change impacts adaptation is not considered (White et al., 2011).

We investigate the impact of climate change, allowing for adaptation, in the Wheatbelt region of Western Australia. In this region the agricultural growing season is limited by moisture availability and as the region is predicted to warm and dry with climate change (e.g., Moise and Hudson, 2008; Turner et al., 2011) the dryland agriculture practiced there is potentially vulnerable. Climate change may already be affecting the region: average growing-season rainfall (May to October) has declined by more than 10% since the 1970s (Ludwig et al., 2009). Interestingly, despite this, farms in the region experienced high yield and productivity growth in the 1980s and 1990s (Islam et al., 2014). However, more recently, average yields appear to have stabilised (Stephens et al., 2012; Turner et al., 2011).

Studies of the economic impacts of climate change that incorporate agricultural adaptation need to encompass: (a) the impacts of climate change on the production of outputs in various possible production systems, and (b) an economic assessment of the impact of these production changes and the options for adaptation that are available to the farmer. Aspect (a) is often addressed using detailed plant and/or animal simulation models, and there have been a number of studies of this type for the case-study region (Anwar et al., 2015; Asseng et al., 2004; Asseng and Pannell, 2013; Farre and Foster, 2010; Ludwig and Asseng, 2006; Ludwig et al., 2009; Moore and Ghahramani, 2013; van Ittersum et al., 2003).

Aspect (b) has been much less thoroughly researched for the study area. There are two main approaches that can be used to investigate it. The first is to identify packages of adaptations that are of interest and then simulate the economic consequences of each package (e.g.,

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Crimp et al., 2012; Ghahramani et al., 2015). An advantage of this approach is that the modeller has complete control over which adaptations are simulated, allowing transparent analysis of particular strategies that are of interest. Deciding which packages of adaptations to simulate can be problematic though (White et al., 2011), particularly in complex mixed farming systems such as those found in the case-study region. The modeller may not be able to anticipate which of the many potential combinations of adaptations are most likely to be worth assessing.

The second approach is to use optimisation to automatically assess all of the available combinations of adaptations. The obvious advantage is avoiding the need for numerous simulations to identify the adaptations that best meet the farmers' economic objectives (Klein et al., 2013). However, the analysis may be less transparent than under the simulation approach, and the objective function used in the optimisation model may not match that of all farmers.

In this study, we utilise process-based simulation models for the first phase, and extensively modify an existing bioeconomic whole-farm optimisation model for the second. We judged that the very large number of production options available in our case-study region means that the advantages of the optimisation approach outweigh its disadvantages. Also, previous analyses of climate change impacts on the case-study region have tended to consider impacts on a solitary crop or enterprise in isolation. Our use of a whole-farm model allows the simultaneous consideration of impacts on all elements of a typical farming-system in the region. Amongst other things, this allows adaptation in the form of changing land use to be represented in our study (Reidsma et al., 2015).

Our aim is to explore potential impacts of future climate change on production and profitability in the West Australian Wheatbelt. Specifically we address the following questions: 1) What is the impact on farm production and profits under a range of realistic climate scenarios over the next 15 to 35 years?; 2) Which currently available adaptations are most effective in moderating any adverse effects or exploiting positive effects, and to what extent do they improve farm profits?; Finally, 3) What increase in prices or yields would be needed to maintain profits equivalent to the no-climate-change scenario?

2. Methodology

2.1. Study area

The Western Australian Wheatbelt region accounts for approximately 40% of the wheat and 11% of the wool exported by Australia (around 5% and 7% of the wheat and wool traded internationally—ABARES, 2013). Our study area is the central part of this Wheatbelt region, around the township of Cunderdin (Fig. 1). This area has a Mediterranean-type climate with long, hot and dry summers and cool, moist winters. Historically annual rainfall is between 330 and 400 mm, approximately 75% of which falls during the May to October growing season.

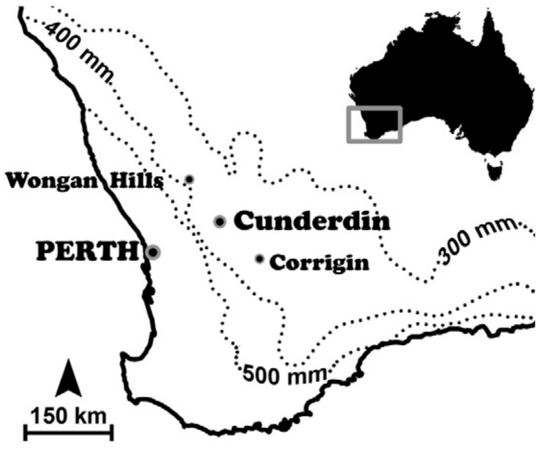

Fig. 1. Our Central Wheatbelt study area is centred on the Cunderdin Township. Precipitation isohyets are based on historical observations.

Farms in the area are commonly 2000–4000 ha, of which 65–85% is typically sown to annual crops in May and June; the remaining areas are pastured, supporting sheep for meat and wool production. Farming systems are solely rain-fed, and after harvest in December, the remaining crop residues are utilised in-situ as dry fodder. Once this feed supply is exhausted, livestock receive a grain-based supplementary ration until adequate green pasture becomes available after the onset of winter rains (Rowe et al., 1989).

2.2. Farm-level modelling

The economic impact of climate change was evaluated using MIDAS (Model of an Integrated Dry Land Agricultural System—Kingwell and Pannell, 1987; Morrison et al., 1986). MIDAS has been used extensively to explore the impacts of innovations, policy changes and environmental degradation on mixed cropping–livestock farms (e.g., Doole et al., 2009; Kragt et al., 2012; Monjardino et al., 2010; Robertson et al., 2010). MIDAS is deterministic, based on an 'average' weather-year in the study area (although the region's Mediterranean-type climate is semi-arid, historically, the variability in this climate has been relatively low, making the steady-state modelling framework of MIDAS justifiable—Kingwell, 2011).

MIDAS uses a linear-programming algorithm to maximise farm net return subject to resource, environmental, and managerial constraints, including machinery capacity and the availability of land, labour and capital. MIDAS contains approximately one thousand activities, including: a range of rotations with different sequences of crops and pasture for each soil type; feed supply and utilisation by different classes of livestock; different crop sowing dates (and yield penalties for delays to sowing); cash flow recording and; machinery and overhead expenditures. MIDAS captures biological and technical relationships at the farm-level, particularly interdependencies between enterprises such as the benefits of nitrogen fixation, the yield-enhancing (e.g., disease-break) effects of crop rotation, the value of crop residues as animal feed, the effects of cropping on subsequent pasture growth and the effect of weed burdens for subsequent crops.

For this study the Central Wheatbelt MIDAS used in recent studies (Kragt et al., 2012; Thamo et al., 2013) was updated to reflect changing trends by increasing the capacity and value of machinery. Farm size was also increased to 3200 arable hectares. The MIDAS farm contains eight different soil types with varying production characteristics, as farms in the study area typically contain a mix of soil types (for descriptions of, and areas assumed for each soil type see the Supplementary Material). Land-uses represented in the model include rotations of wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), oats (*Avena sativa*), lupins (*Lupinus angustifolius*), canola (*Brassica napus*), and annual legume-based pastures. The annual net return we report represents the pre-tax profit after deducting variable costs, as well as non-cash costs like depreciation, and fixed overheads like household expenses and hiring of professional services. For the present study we added the option of retiring land from production, the rationale being if climate change renders agricultural production unprofitable, a producer's optimal response may be to 'retire' from production their least productive land to minimise their losses. Unlike the temporary fallowing of land, land retirement is purely a loss-minimisation activity that neither generates income nor incurs costs (overheads associated with maintaining the farming enterprise as whole are still incurred).

The predicted impacts of changes in climate and atmospheric CO_2 levels (hereafter called 'climate scenarios') on farm production were incorporated into MIDAS. This was done by using biophysical simulation models (described in Section 2.4) to estimate the effect of a given climate scenario on agricultural production, and then based on these results, the growth potential of crops and pastures in MIDAS were scaled.