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The value of adapting to climate change in Australian wheat farm systems: farm to cross-regional scale

Afshin Ghahramani[a,*], Philip N. Kokic[b], Andrew D. Moore[a], Bangyou Zheng[c], Scott C. Chapman[c], Mark S. Howden[a], Steven J. Crimp[a]

[a] CSIRO Agriculture Flagship, GPO Box 1600, Canberra ACT 2601, Australia
[b] CSIRO Digital Productivity & Services Flagship, CSIRO, GPO Box 1700, Canberra, Australia
[c] CSIRO Agriculture Flagship, Queensland Biosciences Precinct, 306 Carmody Rd., St. Lucia QLD 4067, Australia

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ABSTRACT

Wheat is one of the main grains produced across the globe and wheat yields are sensitive to changes in climate. Australia is a major exporter of wheat, and variations in its national production influence trade supplies and global markets. We evaluated the effect of climate change in 2030 compared to a baseline period (1980–1999) by upscaling from farm to the national level. Wheat yields and gross margins under current and projected climates were assessed using current technology and management practices and then compared with 'best adapted' yield achieved by adjustments to planting date, nitrogen fertilizer, and available cultivars for each region. For the baseline climate (1980–1999), there was a potential yield gap modelled as optimized adaptation gave potential up scaled yields (tonne/ha) and gross margins (AUD $/ha) of 17% and 33% above the baseline, respectively. In 2030 and at Australian wheatbelt level, climate change impact projected to decline wheat yield by 1%. For 2030, national wheat yields were simulated to decrease yields by 1% when using existing technology and practices but increase them by 18% assuming optimal adaptation. Hence, nationally at 2030 for a fully-adapted wheat system, yield increased by 1% and gross margin by 0.3% compared to the fully adapted current climate baseline. However, there was substantial regional variation with median yields and gross margins decreasing in 55% of sites. Full adaptation of farm systems under current climate is not expected, and so this will remain an on-going challenge. However, by 2030 there will be a greater opportunity to increase the overall water use and nitrogen efficiencies of the Australian wheat belt, mostly resulting from elevated atmospheric CO_2 concentrations.

1. Introduction

Wheat production is known to be sensitive to variations in both temperature and rainfall (Lobell et al., 2011). Changes in climate are expected to have varying impacts in different regions of the globe although negative impacts are expected to be more common than positive ones (Porter et al., 2014). A reduction in Australian wheat production can potentially affect global food security (FAO, 1996) and its global availability (Ingram, 2011), as Australia is the fourth largest wheat exporter in the world (Connor et al., 2011). Its production can affect the global food market, as shown by increased global wheat prices during the drought between 2002 and 2009 (Lobell et al., 2011).

Changes in climate over the past century interact with advances in agricultural technology and farming systems (Lobell et al., 2011). As, greater changes in climate are predicted in the near future compared to the changes of the late 20th century (Parry et al., 2007) continued technology and farming systems adaptations will be needed.

A viable response strategy for regions such as the Australian wheatbelt where climate change is largely anticipated to be negative is via improvement of farm management practices to offset anticipated declines in production and profitability (e.g. Stokes and Howden, 2010). Climate adaptation is the process of adjustment in natural or human systems in response to actual or expected climatic stimuli to moderate harm or exploit opportunities (Parry et al., 2007). In farming, management adaptations vary resource use in accordance with changes in climate and its seasonal variability to gain benefit for example from increased yield (Bassu et al., 2009; Hunt and Kirkegaard, 2012). However, there often exists a 'yield gap' between actual farm practices and

* Corresponding author. Tel.: +61 2 624 648 92.
E-mail address: af.ghahramani@csiro.au (A. Ghahramani).

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those which would maximise benefits. This is important when assessing climate change scenarios so as to not conflate closing the existing yield gap with optimised adaptation under climate change (Stokes and Howden, 2010).

Some potential benefits from changes in climate are related to fertilization by elevated atmospheric CO_2, which is an important part of the climate change impact in water-limited environments i.e. the great majority of Australian production (Tubiello et al., 2007). The primary adaptation opportunities arise from managing soil water more efficiently through the growing season (Kirkegaard et al., 2014) by choosing variety, sowing time, sowing density and fertilizer timing and amount. It should be noted that management strategies that are optimized for present-day climate may not necessarily be optimal for future climate. This suggests that it is worthwhile exploring optimal adaptation under projected climate.

Previous evaluations of climate change impacts on Australian wheat production have indicated a substantial decline in production in Western Australia (Ludwig et al., 2009) and a decrease in production in the southern part of the Australian wheatbelt (Ludwig and Asseng, 2006), including cross-regional assessments of impacts and adaptations (Howden, 2002; Howden and Crimp, 2005). However, these analyses of yield and gross margin change have been applied to a limited number of sites and have not included effective methods to scale up the analyses to a national level to provide industry and policy makers with a clearer insight for high level planning.

In this paper we evaluate the impact of climate change and the effectiveness of adaptations for projected climate scenarios in 2030 relative to a historical baseline of 1980–1999 (with current management), in order to estimate the value of adaptation in terms of production and financial returns. We use a bottom-up methodology that optimally exploits local knowledge and data (van Ittersum et al., 2013) and requires extensive biophysical system modelling. We predict wheat production/gross margin in 2030 through the biophysical modelling of unit scale results and use farm survey data and a survey estimation method to upscale results to a cross-regional/ national level.

2. Methods

The impacts of climate change and adaptations were evaluated in terms of the resulting yield (per ha) and gross margin (per ha), which is the difference between estimated income and the fixed and variable costs of production, excluding capital costs. The adapted yield (AY) and adapted gross margin (AG) are upper limits for fully enhanced systems with all adaptation strategies (in this study, all currently-existing technologies) at the efficiency frontier (EF). For historical climate, lower limits are the historical yield (HY) and historical gross margin (HG) under current practice. For future climate we defined lower limits as current practice yield (CPY) and current practice gross margin (CPG). AY and AG are reported in comparison with those of HY and HG for the historical baseline and CPY and CPG for the future. It should be note that AY and AG are fully adapted (enhanced) systems on the EF. These modeled values may not be achievable due to biophysical, management, social, or economic constraints. Here, all projections in 2030 have been associated with the effect of elevated atmospheric CO_2 unless otherwise indicated. Concepts, abbreviations, impact, and adaptation framework are presented in Fig. 1.

2.1. Study area and sites

The study area is the Australian wheatbelt (Fig. 2). Averaged over 1980–1999, about 10.2 million ha of this area has been planted to wheat (ABARES, 2003). Across this region the climate and soil types (Table 1) and cultivars (Table 2) vary widely. A set of

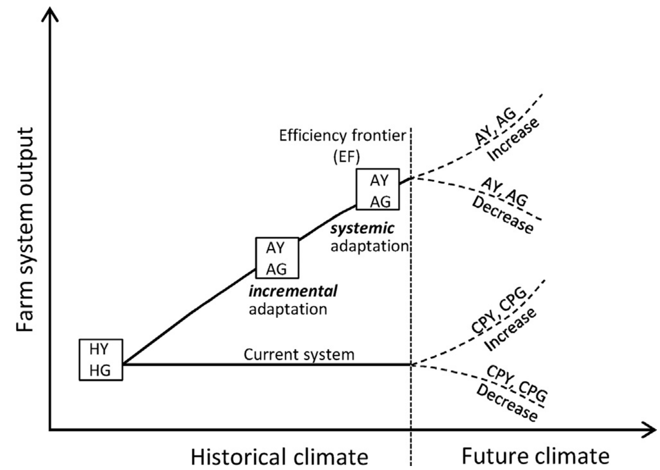

Fig. 1. Concepts and frame work for climate change impact and adaptation analysis. HY: historical yield, HG: historical gross margin, AY: adapted yield, AG: adapted gross margin, CPY: current practice yield, CPG: current practice gross margin. AY and AG are on the efficiency frontier when implementing systemic combination of incremental adaptation options from current technologies.

representative wheat farming sites was therefore selected by aggregating statistical areas level 2 within the wheatbelt (SA2s, Australian Bureau of Statistics, 2011) into a set of 30 regions (Fig. 2) so that each region had approximately equal gross value of average agricultural production (GVAP). SA2s were grouped according to their average annual rainfall and land use (i.e. the proportions of GVAP attributable to cropping). A single location (Fig. 1) was then selected from each of the 30 regions to ensure a good spread of sites across the wheat belt (as in Moore and Ghahramani, 2013). The baseline climate was 1980–2010 at each location as recorded by the Bureau of Meteorology.

2.2. Climate change scenarios

Research has demonstrated that global carbon dioxide (CO_2) emissions, atmospheric CO_2 concentrations, sea-level rise and global temperatures are already tracking along the upper bounds of the previously-projected range (Peters et al., 2012). We therefore used two high-emissions CMIP3 (Meehl et al., 2007) scenarios (A1FI and A2) with high and medium sensitivity that allowed us to sample across the more likely range of possible future climates in the focus year of 2030 using six global climate models (GCM): ECHAM 5 (Roeckner et al., 2003), GFDL 2.1 (Delworth et al., 2006), HADCM3 (Pope et al., 2000), HADGEM1 (Johns et al., 2006), MIROC-H (Burgess et al., 2012), MRI-GCM 232 (Yukimoto et al., 2001). These GCMs were selected based on performance and ranking by 11 criteria (Crimp et al., 2010) of which the most important were (i) demerit points based on criteria for rainfall, temperature and mean sea level pressure (Suppiah et al., 2007), (ii) *M*-statistics representing goodness of fit at simulating rainfall, temperature and mean sea level pressure (Watterson, 2008) and (iii) predictive skill for daily rainfall over Australia (Perkins et al., 2007). At the time of analysis Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2012) projections were not yet available.

Projections from each GCM were statistically downscaled using the quantile matching (QM) method (Kokic et al., 2013; Burgess et al., 2012) to produce daily weather data sequences for each of the 30 locations. The QM algorithm works by modifying historical weather sequences (in this case for 1980–2010), and therefore preserves spatial correlations in climate; for example a drought at one location is likely to coincide with a drought at nearby locations. This is essential when attempting to scale up effects across the country. Atmospheric CO_2 concentrations of 350 ppm for historical