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Scenarios for Australian agricultural production and land use to 2050

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ABSTRACT

Australian agricultural land use and production have evolved within an economic and environmental context that may change substantially in terms of productivity rates, resource scarcity and degradation, greenhouse gas abatement policy, climate change, and global demand. We used an integrated systems modelling approach to explore the response of Australian land use and agricultural production to these changes from 2013 to 2050. We found potentially large transitions in spatial and temporal patterns of land use, agricultural production, output rates, and profitability. New land uses such as carbon plantings, biofuels and bioenergy, and environmental plantings competed with food and fibre production, reducing its area. Global outlooks, including the strength of action on climate change and population assumptions, had a strong influence. Capacity constraints and adoption inertia reduced and delayed land use change. Agricultural production and land use were sensitive to productivity assumptions. Despite the competition for land from new land uses, agricultural production increased under most settings, with greatest impact from land use transitions concentrated on livestock production. Agricultural profits also increased under most settings due to higher prices and output rates. Negligible land use change was observed with carbon payments below \$50 per tCO_2-e, and significant change did not occur before 2030 in any but the unconstrained, high-abatement scenarios. We conclude that transformative land use change is plausible but high levels of food/fibre production can co-exist with non-food land uses motivated by market responses to global change and domestic policy. Thereby, the Australian land sector can continue its significant contribution to global food security while responding to new economic opportunities. Policy settings can influence these outcomes through reducing infrastructure constraints, strategies for enhancing adoption, and research and development in agricultural technology and productivity. Due to the long time frames required to change attitudes and land use and management practices, consideration of the possible impacts of global change on agriculture and potential policy responses is timely.

1. Introduction

Ensuring global food security is the defining challenge for agriculture in the 21st century (Foley et al., 2011). Growing human population, rising incomes, and changing patterns of food preferences and consumption will increase global demand for agricultural products (Godfray et al., 2010; Kastner et al., 2012). Land for agricultural expansion is limited (Pardey et al., 2014) and competition from other land uses will impact on the existing land base (Bryan et al., 2013; Harvey and Pilgrim, 2011; Smith et al., 2010). Numerous challenges threaten future agricultural productivity, including climate change and ongoing natural resource degradation (Arrouays et al., 2014; Ausubel et al., 2013; FAO, 2011; Fischer et al., 2014; Sonneveld and Dent, 2009). Rising food demand and mounting production challenges have prompted a reassessment of global agricultural capacity to ensure food security (Kastner et al., 2012; Nelson et al., 2010). Australia is a significant food exporter and understanding the possible impact of these multiscale drivers and risks for Australian food production is essential for informing public debate and policy for the future of agriculture, land use, and its contribution to global food security.

The century-long fall in global food prices was replaced with consistent price rises from 2004 (Fischer et al., 2014). Recent food shortages resulting from sharp food-price rises (or *shocks*) have had global impacts (Lagi et al., 2011) adding to the already large number of food-insecure people (FAO et al., 2013). While food insecurity has many dimensions, the relationship between food price and food insecurity is swift and direct. Ivanic et al. (2012) estimated that the food price shocks of 2008 and 2011 led to an average global food price rise of 118 and 37%, and a net increase in people living in extreme poverty (Ravallion et al., 2009) of 105 million and 44 million, respectively. A broad set of drivers have contributed to these recent price shocks including extreme

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climatic events, an increased tendency for countries to restrict exports and practice other price insulation mechanisms to ensure their own food security (Anderson et al., 2013), and through biofuel mandates to increase energy security (Carter et al., 2011). Food insecurity has been associated with significant social consequences including increased mortality rates, social unrest, and geopolitical upheaval (Lagi et al., 2011).

The world's population will continue to grow for at least the next few decades (United Nations, 2013b) and food demand in aggregate is predicted to grow by 50–80% by 2050 (Keating et al., 2014). Recent trends seem likely to continue, not only in increased demand for food (or kilojoules) in general (FAO, 2011), but also in significant increases in the food traded per person globally (Schmitz et al., 2012), and in broadened food preferences (Alexandratos and Bruinsma, 2012; Hajkowicz et al., 2012). Arable land used for agriculture has increased slightly over recent decades, while the area of arable land per person has declined from 0.34 ha/person in 1973 to 0.23 ha/person in 2008 (extracted from FAOSTATS in 2013). Strategies for meeting future food demand include increased productivity on existing lands and some increased land for food production (Fischer et al., 2014; Springer and Duchin, 2014). However, land degradation continues (FAO, 2011), input resources are likely to become scarcer and more expensive (Odegard and van der Voet, 2014), and the impacts of climate change and its mitigation are complex (Challinor et al., 2014; Falloon and Betts, 2010; Gornall et al., 2010).

At the same time, increased demands are being made of the world's landscapes for other ecosystem services (Bryan et al., 2013; Law et al., 2014; O'Farrell and Anderson, 2010). Garnaut (2011), in assessing Australia's policy options to respond to global climate change, observed that much of the response in the first few decades could arise from the land sector. Significant impacts on land use patterns could potentially arise both from climate change and its mitigation through biosequestration to reduce atmospheric concentrations of greenhouse gases and other mechanisms such as biofuels. Many other studies have also documented and projected the need for increasing diversity of services from agricultural land (Bryan and Crossman, 2013; DeFries et al., 2004; Gordon et al., 2010).

Historically, Australian agricultural production and productivity have risen in response to pressure from declining terms of trade (1.6% per year on average across crops and livestock from 1961 to 2006) (Sheng et al., 2013). This has been driven largely by innovation expressed as continuous adoption of new technologies (new genotypes, changes in land management, increased resource-use efficiency), by increases in land and labour productivity, and by efficiencies achieved via increasing the scale of farm operations (ABARES, 2014). The level of production and the distribution of land use have, in the past, responded to a range of other factors including structural adjustment programs, price support schemes, and subsidies in both domestic and international settings. While domestic support for agriculture has declined substantially over recent decades to approximately 3% of gross farm receipts in 2013 (OECD, 2013), continuing high levels of support internationally impact on Australian production and land use through the resultant distortions in markets and prices (Baffes and Gorter, 2005). In addition, production is influenced by irrigation establishment, infrastructure development, and resource availability. Climatic extremes such as prolonged drought and significant flood events and price volatility affect both the level of production and farmers' land use choices (Gornall et al., 2010).

Australia is currently a major exporter of grain and animal protein. About 65% of Australia's agricultural production is exported, and grain ($6.0B, 12% of world exports), beef ($6.8B, 17%), and wool ($2.8B, 67%) are significant in world trade (ABARES, 2012). It has been a consistent policy aim within Australia to maintain this level of excess production and exports, partly as a contribution to satisfying global food demand (Commonwealth of Australia, 2014). This net excess of production over domestic demand has been built on a sustained increase in productivity within the major agricultural industries. However, mirroring trends in other industrialised countries (Fuglie and Nin-Pratt, 2013), the rate of increase in total factor productivity of Australian agriculture has slowed since the mid 1990s. The climate-adjusted total factor productivity increase declined from 2.15% pa prior to 2000 to 1.06% pa over the following decade for cropping (Hughes et al., 2011). Lower levels of productivity increase, and even some absolute declines, were observed in other agricultural industries. This decline was primarily attributed by Sheng et al. (2011) to less emphasis on agricultural R&D investment.

These are complex challenges for agriculture, land use, and food production, and integrated analysis of possible futures for agricultural production, land use, and the contribution to meeting global food demand is urgent for Australia and internationally (Falloon and Betts, 2010; Hibbard and Janetos, 2013). Undertaken as part of the Australian National Outlook (Hatfield-Dodds et al., 2015a), we explored the interactions and implications of three key issues for agriculture: the long-term outlook for food demand, increasing competition for land, and the impact of productivity changes. We analysed interactions and alternatives using a scenario approach from 2013 to 2050. While we do not attempt to predict the future, scenarios can usefully illuminate potential responses to combinations of policy, markets, and actions (Audsley et al., 2015; Herrero et al., 2014; Mancosu et al., 2015; Odegard and van der Voet, 2014; Pardey et al., 2014; Rutten et al., 2014; Santelmann et al., 2004). Our analysis involved a novel integration of multiple systems models, linking global, national, and local scales. We explored scenarios enveloping plausible ranges in climate change and climate change policy, national and global population, and the carbon, energy, and food prices consistent with these settings. Based on these land use drivers, we assessed potential agricultural production and land use competition between 23 existing agricultural land uses and seven new land uses for 72 unique scenario combinations of four global outlooks, three productivity rates, three adoption hurdle rates, and two capacity constraint settings. While many forces will ultimately conspire to constrain and shape actual futures, understanding influential drivers and their interactions through scenarios is essential for informing future policy and investment decisions to sustain Australian agricultural production and land systems.

2. Methods

2.1. Study area

The study area covered Australia's intensively managed agricultural lands; an area of approximately 85 million ha stretching from central eastern Queensland to the wheat belt of southern Western Australia. The extent of these lands was defined using the National Land Use Map of Australia Version 4 (ABARES, 2010) and the National Vegetation Information System (ESCAVI, 2003). Significant agricultural production occurs outside the study area, particularly extensive beef cattle production on natural pastures in northern Australia. Isolated pockets of irrigated production (e.g. Ord River scheme) were also omitted where they were not contiguous to the main production areas. The study area includes 33 Mha of beef cattle, 18 Mha of sheep, 3 Mha of dairy and 25 Mha of grain production (Fig. 1) (Marinoni et al., 2012). The much smaller areas of irrigated production of high value crops provide a disproportionately high value of production (e.g. in the Murray–Darling Basin 80% of the profit comes from 5% of the agricultural area) (Bryan et al., 2009).

2.2. Modelling framework

We used a set of models to characterise aspects of global and domestic society, economy, and environment (Fig. 2), loosely coupled and interacted such that outcomes in each model may influence other models. At a global level, we explored the dimensions of uncertainty