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The impacts of expansion and degradation on Australian cropping yields—An integrated historical perspective

Graham M. Turner [a,b,*], Michael Dunlop [a], Seona Candy [c]

[a] CSIRO Ecosystem Sciences, Canberra, ACT, Australia
[b] Melbourne Sustainable Society Institute, University of Melbourne, Parkville, Vic, Australia
[c] Victorian Eco-Innovation Lab, University of Melbourne, Parkville, Vic, Australia

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ABSTRACT

Using a 'stocks and flows' model of Australian cropping we show that the expansion of aggregate cropping area has effectively masked landscape degradation impacts associated with continual production activity on "ageing" land. We estimate yield loss from combined land degradation to have increased to 9%, though the aggregate impact has effectively been masked by the introduction of new land. The model tracks the vintage of land since its first introduction to the agricultural system and calculates landscape degradation for four modes (dry-land salinity, irrigation salinity, acidification, and soil structure decline) according to historical production and ameliorating activities on each vintage. The model is calibrated with over 140 years of varied historical data from the 1850s. Modelled farm-gate production volumes also incorporate technological factors, such as genetic and other yield increases. Despite the introduction of many technological advances in the cropping industry through the middle of the 20th century, production yields of Australian cereal grain remained relatively unchanged for decades. This can be explained by the rapid ageing and degradation of the cropping land due to a period of halted expansion. This perspective has important implications for future scenarios of the Australian cropping industry, which are unlikely to maintain land expansion at the long-term average of about 2% pa. Without major change, land degradation in our model results in yield loss of nearly 30% by 2060.

1. Introduction

Agriculture has contributed enormously to the economic growth of Australia in the last 200 years, and continues to be a major source of food and fibre for international and domestic markets, as well as export income (Pollard, 2000). However, one of the most notable features of this sector over this history has been the considerable increase in the amount of land and water resources used.

While these resources are ostensibly renewable, in practice the past use of land, water and ecosystem resources has frequently not been in a renewable manner; *Australia State of the Environment* (ASEC, 2002). The National Land and Water Resource Audit[1] (NLWRA, 2002), including the *Australian Natural Resources Atlas* and the series of Assessment Reports, reveals evidence of wide-scale erosion of Australia's natural resource capital. Increasing dryland salinity and declining river health are two well-recognised examples that illustrate the widespread and complex nature of the issues. While public attention to dryland salinity has waned over the past decade (due largely to decreased rainfall helping to lower saline water tables), the impact of several modes of land degradation on crop yield remains significant.

In some other major crop producing regions, yields appear to have reached a plateau (Grassini et al., 2013). Yet to feed the potential future global population, future yield growth needed to 2030 is estimated to be similar to past global rates (of about 40–60 kg/ha/a for key cereal crops) (Gregory and George, 2011). Evidently there is a pressing need for research into how to close the 'yield gap' (between potential and average actual yield) (van Ittersum and Cassman, 2013), though this is likely to be challenging due in part to questions of regional differences and scale issues (van Ittersum et al., 2013).

Our modelling research sought to explore future scenarios of the Australian agricultural industry, with a focus on crop production and sustainability (Dunlop and Turner, 2003; Dunlop et al., 2002). This was grounded in an integrated understanding of the history of Australian agriculture and the grains industry, which does more than simply set the scene for possible future scenarios, as we present in this paper. Historical developments impose constraints on possible future actions, through a sort of inertia associated with stocks of land. Additionally, important lessons can be drawn from historical developments, especially when considered in an integrated framework that captures the interactions between factors such as land intensification, landscape degradation, and water use.

* Corresponding author at: CSIRO Ecosystem Sciences, Canberra, ACT, Australia.
E-mail address: graham.turner@unimelb.edu.au (G.M. Turner).
[1] http://www.nlwra.gov.au.

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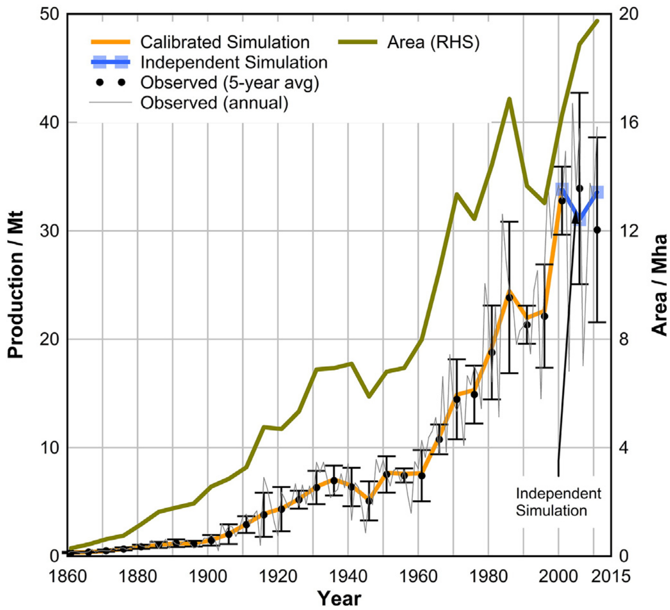

Fig. 1. Comparison of simulated cereal grain production with observed data (thin line shows annual data; solid circles with standard deviation error bars show 5-year averages). Simulated production is calibrated to the observed data up to 2001. Beyond this, independently simulated 5-year production for 2006 and 2011 (square symbols with blue line) is close to observed production. Area of cereal grain cropping is also shown (RHS). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In this paper, we first review the history of Australian agriculture and the grains industry from a nationally aggregated view of key factors and indicators, pulling these together into an integrated picture that reveals the long-term drivers of change. This suggests the key factors and relationships required in our model, which is briefly described. Particular emphasis is given to explaining the part played by the age structure of crop and pasture land, and the associated concept of landscape condition or degradation. As in other sectors of the economy that are based on stocks of infrastructure and resources, the age structure concept and its implications are key elements for understanding the historical progress of the grains industry, and for designing future scenarios. We document how these key elements were calibrated, and show how historical crop (cereal) yield has been impacted. Our analysis focuses on cereals as the dominant Australian crop, though we also present data for broader intensive agriculture (all crops and sown pasture) due to the integrated nature of our system modelling and analysis. Some illustrative implications of constraints in land expansion on future yield dynamics are explored using the model, and we finish by discussing possible modelling and research issues/questions.

2. Integrated long-term overview of progress in the Australian grains industry

Many technological, process and environmental developments have occurred in the Australian grains industry over the past 150 years. We consider the various factors in an integrated manner so that we may identify the slow moving changes that are likely to impact on the future of the grains industry. In addition to the historical data assembled in our model, this broad overview draws on a number of historical reviews of the agricultural sector (Camm and McQuilton, 1987; Pollard, 2000; Shaw and Davidson, 1995; Tribe and Peel, 1988).

An overview of the impact of technology (and other factors) on the productivity of the grains industry is presented in the national average cereal grain yield (t/ha) (NLWRA, 2001) (Fig. 2a and the bar chart depicting the extent of major events and developments relevant to the grains industry over the same time period (Fig. 2b). The graph of cereal grain yield shows annual data as well as moving averages calculated for 5 and 15 year periods, with the longer averaging recommended for Australia's highly variable production (van Ittersum et al., 2013). By smoothing out the short-term fluctuations, the moving averages clearly show the leaps and plateaus of yield over the past century (in contrast with the impression of a continual linear increase since 1900 as presented in the NLWRA (2001)).

Broadly, the trends shown in Fig. 2a indicate four historical periods of different yield development.

- From 1850 to about 1900 there was a strong decrease in the yield. This is typically attributed to nutrient depletion of soils (Burch et al., 1987; Hamblin and Kyneur, 1993), although the situation was unlikely to be this simple, as discussed below.
- After the turn of the century there is rapid increase in the yield over one or two decades. By 1930 the (long-term) yield increase from that at 1900 was approximately 70%.
- However, this trend for rapid increase saturates so that for the next four decades there was relatively little long-term change in average yield, increasing by about 10%.
- In stark contrast, a powerful yield increase of roughly 70% occurred over the period from 1970 until the end of the 20th century. Earlier research (Burch et al., 1987; Hamblin and Kyneur, 1993) depicts this period as a second saturating trend.

Previous reviews ((Burch et al., 1987; Hamblin and Kyneur, 1993), based on (Donald and Williams, 1982)) of the trends in wheat yields from the late 1800s to the late 1900s have also identified distinct phases, namely a decreasing period to 1900 followed by two saturating trends. These reviews also indicate the introduction of a number of technological factors or crop management techniques that have impacted on crop productivity. Despite raising concerns that land degradation underlies at least some of the limited growth in yield, these reviews have not explicitly considered the influence of the introduction of new land, or more specifically, the age of the extant cropping land.

Comparison of the bar chart of Fig. 2 with the yield curve highlights the importance of various drivers (including but not limited to technology) on yield improvement. An important but evidently short-term (1–10 years) effect is the impact that strong droughts (an 'environmental climate' factor in Fig 1) have on the yearly yield. In comparison, droughts that are classified as medium or low (not shown on the bar chart) (see NLWRA, 2001) do not have a substantial affect. This difference points to the importance of geographic variation: the impact of less substantial droughts is ameliorated by higher yields in areas that are not drought affected. Other factors operate over longer periods, as the following review chronicles.

2.1. 1850–1900

Prior to the beginning of the 20th century there was a general expansion of agricultural area—from 1850 to 1900 the area increased by a factor of more than 25 times for cereal grain. This was accompanied by a considerable decline in the overall productivity as shown by the average yield from 1850 to 1900. The average yield decreased by roughly 70% over this time.

The yield reduction is commonly attributed to soil nutrient depletion resulting from sustained poor farming practices (e.g., Donald and Williams, 1982; Hamblin and Kyneur, 1993). In particular, the practice of incorporating fodder crop rotations was not employed even though this was recognised (in the UK and Europe) as an important way to provide nutrients through manure application and nitrogen fixation (Henzell, 2007). Consequently, continuous cropping led to nutrient depletion. Other factors may have played a role. For instance, expansion into areas of less fertile soils and the use of grain varieties not suitable for the different soil and climatic conditions have also been implicated