Climate change severely affects wheat yield trends across southern Australia, whereas sorghum yield trends surge.

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Abstract

A review of productivity changes across the Australian grain-belt was commissioned by the GRDC to update a phase 1 report based on data up to 2000/01. Operational crop forecasting systems were used to assess more recent cropping performance and what were the main drivers of change. This paper will present the findings of this review and will concentrate on spatial and temporal trends in the main winter and summer crops, wheat and sorghum. A number of key conclusions arise. Firstly, the rate of wheat yield increase (yield trend) declined rapidly from 2.1% per annum at the end of the 1990s, to only 0.6% at the end of the 2000s. This decrease in the rate of yield improvement occurred in the four southern mainland States at the same time that there was a shift to a drier and more variable climate. In Queensland the wheat yield trend actually increased as yield variability decreased. Eighty percent of the variance in the change in wheat yield trends compared to phase 1 was related to yield variability, making variability a major driver of crop performance. In association with this, two thirds of this variance in the change in wheat yield trends could be explained with a change in nitrogen fertiliser use in the 2000s. In Western Australia the spatial pattern of wheat yield trends shifted from rainfall amount to frost risk in spring. For sorghum, higher genetic gains, a shift in emphasis from wheat to sorghum, and higher rates of nitrogen application, all contributed to the national sorghum yield trend increasing from a high 3% at the end of the 1990s, to 3.9% at the end of the 2000s. Sorghum had much greater gains in water use efficiency than wheat and appears to be less affected by climate change.

Key Words

Climate impact, Technology, variability, water use efficiency, drivers, nitrogen

Introduction

Hamblin and Kyneur (1993) and Cornish et al. (1998) found low or static wheat yield trends across many drier areas of the Australian wheat-belt between 1950 and 1993, especially the northern GRDC zone. Low soil fertility, largely related to inadequate soil nitrogen (N), low rates of N fertiliser application and a low proportion of grain legumes in rotation were considered important factors.

A decade later a National Land and Water Resources Audit (NLWRA, Stephens 2002) and a GRDC commissioned review of productivity changes (Beeston et al. 2006) found large gains in crop yields (48-100 kg/ha/yr) in the 1980s and 1990s in wetter shires of Western Australian, South Australia, Victoria, and the southern and north-eastern areas of New South Wales. This was related to a change in farming systems where farmers progressively switched to early sowing of semi-dwarf varieties, herbicide control of weeds, better tillage techniques, increased N inputs, and more grain legumes and oilseeds in rotation (Angus et al. 2002; Anderson et al. 2005). The lowest yield trends (0-12 kg/ha/year) were found where the highest yield variability was found in Queensland, the northern Eyre Peninsular, central New South Wales and north central Victoria (Stephens 2002). Sorghum trends were high in the 1990s in northern New South Wales as farmers dramatically increased N after noticing carryover of N between winter/summer crops (Stephens 2002; Potgieter et al. 2005). In contrast, sorghum yield trends were low in Queensland due to severe droughts restricting N inputs and better land being planted to cotton (Stephens 2002; Potgieter et al. 2005).

In 2009, the GRDC commissioned an analysis of grain productivity changes (Stephens et al. 2011) to update a phase 1 report (Beeston et al. 2005). The first aim of this work was to utilise the DAFWA and QAAFI/UQ regional crop forecasting systems to properly define yield trends in the 2000s. Secondly, the aim was then to investigate what were the drivers of these changes.

Methods

Crop Modelling Analysis

A modelling analysis to examine yield trends was carried out with Western Australian Department of Agriculture and Food's STIN wheat model (Stephens et al., 1989) and the Queensland Alliance for Agriculture and Food innovations (QAAFI, University of Queensland) Oz-Sorghum model (Potgieter et al., 2005). These models calculate a water balance and accumulated stress experienced by the crop through the growing season. With shire data being discontinued from 2001/02 on an annual basis, STIN and Oz-Sorghum were calibrated on representative rainfall stations and statistical sub-division (SSD) yields retrofitted back to 1990/91 based on 2007/08 boundaries. Assuming a linear increase in yields with time, model predicted yields (Y) are calculated by:

$$Y = b_0 + b_1*(SI) + b_2*(year) \qquad (1)$$

where, SI is the respective model stress index, b_0, b_1, and b_2 are the population regression coefficients estimated by the method of least squares. By using this approach, the climate variability is removed via the stress index, leaving edaphic and technological factors contributing to the trend term (b_2). Actual yields were converted into de-trended yields using (b_2) and the variability of de-trended yields was examined through the coefficient of variation. For wheat, we also examined if there was an interaction between climate (moisture stress) and technology at a State scale using the equation:

$$Y = b_0 + b_1*(SI) + b_2*(year) + b_3*(SI*year) \qquad (2)$$

where, b_3 is the additional interaction term estimated by the method of least squares. Both these calibrations were set up for wheat to be calculated over 20-year rolling intervals from 1930-49 to 1989-2008.

Water use efficiency is related to the amount of grain produced per millimetre of total water used in the crop growing period. To assess water use (or production) efficiency (WUE) of shire and SSD yields, actual yields were divided by potential yields (Y_{pot}) defined by French and Schultz (1984) with one third of growing season rainfall lost to evaporation. Since we were more concerned with the changes in WUE this method gave similar results to more complex model calculations, in spite of its limitations.

Other analysis

Modelling analysis was supplemented with ground surveys of consultants and farmers in each region. Spatial maps were also produced of yield variability, changes in N fertiliser application, frost frequency, rainfall changes, crop diversity, and farm business profit. Fertiliser data from the 2000/01 census and the 2007/08 Land Management surveys was spatially aggregated from SSD data into GRDC Agro-meteorological zones in Geomedia. Wheat yield variability data was aggregated up in the same way and both these variables were compared to changes in yield trend at a GRDC agro-ecological zone level.

Results

When the STIN model was calibrated on yields using equation 1 the technological increase in yields for 20-year intervals was graphed through time. The results for the 20 years ending in the 2001 crop and the 2009 crop are shown in Table 1. In all States except Queensland there was a dramatic decrease in yield trends as the calibration of the model was moved forward a decade. In Queensland the percentage change in yields increased over a decade from the lowest percentage increase (0.3%/annum) to the highest (1.1%/annum).

Table 1. Wheat yield trends in kg/ha/year and percentage change per year as a ratio of the long-term average for wheat growing States and Australia.

Period	1982/83 to 2001/02		*1990/91 to 2009/10*	
Region	Kg/ha/yr	%/annum	*Kg/ha/yr*	%/annum
National	34.9	2.1	10.6	0.6
New South Wales	43.7	2.4	3.7	0.2
Queensland	4.3	0.3	14.6	1.1
South Australia	2.1	2.1	14.8	0.9
Victoria	25.7	1.3	3.9	0.2
Western Australia	38.4	2.6	16.3	1.0

The largest decrease in yield trends occurred over south-eastern Australia in New South Wales and Victoria where the largest yield variability occurred in the 2000s. In this region the severe 2006-2008 drought was the main factor behind a -10% to -30% change in water use efficiencies between 2003-2008. In Western Australia the lowest yield trend in the 1980s and 1990s was in the variable northeast, but in the 2000s this shifted to the region of highest frost risk in September and October in the central southern part of the wheat-belt. Compared to the 1990s, this region actually had a slight increase in frost frequency in the 2000s which confirmed anecdotal evidence from farmers in this area that frost had really affected yields.

Thus, climate factors appear to play a major role in affecting crop productivity changes seen over the last decade. This was confirmed when the interaction term in Equation 2 was calculated for 20-year rolling periods with State wheat yields. Through the 1980s and 1990s this term was close to zero, inferring that new technology was not restricted by climate or dependent on it. However, in the 2000s the interaction term jumped to record levels in the four southern mainland States at the same time the standard deviation in yields jumped to a maximum (around 2000). In these regions, the technology of the 1980s and 1990s would be deemed appropriate for the climate resources, but the abrupt climate change in the 2000s imposed severe constraints on technology which has limited yield increases. All across Australia there was a consistent drier May in the 2000s which affected the trend to earlier sowing and the move to more grain legumes in rotation.

To investigate the important role of N fertilisers (Hamblin and Kyneur 1993; Cornish et al. 1998, Stephens 2002), changes in yield variability and N fertiliser application were compared to changes in yield trend between phase 1 and 2 periods. The importance of yield variability in adjusting productivity gains is seen in Figure 1 where the change in yield trend progressively becomes more negative with a larger increase in variability. Tasmania has very small crop areas and was coming off very large yield increases in the earlier period so should be separated from the mainland States. When this is done, eighty percent of the variance in yield trend changes can be explained with the changes in yield variability. National scale fertiliser data was very limited being only available for two separate survey years at the end of the phase 1 period and in 2007/08 (close to end of phase 2). Nevertheless, 67% of the variance in yield trend changes could be explained by the percentage change in nitrogen application between these two surveys.

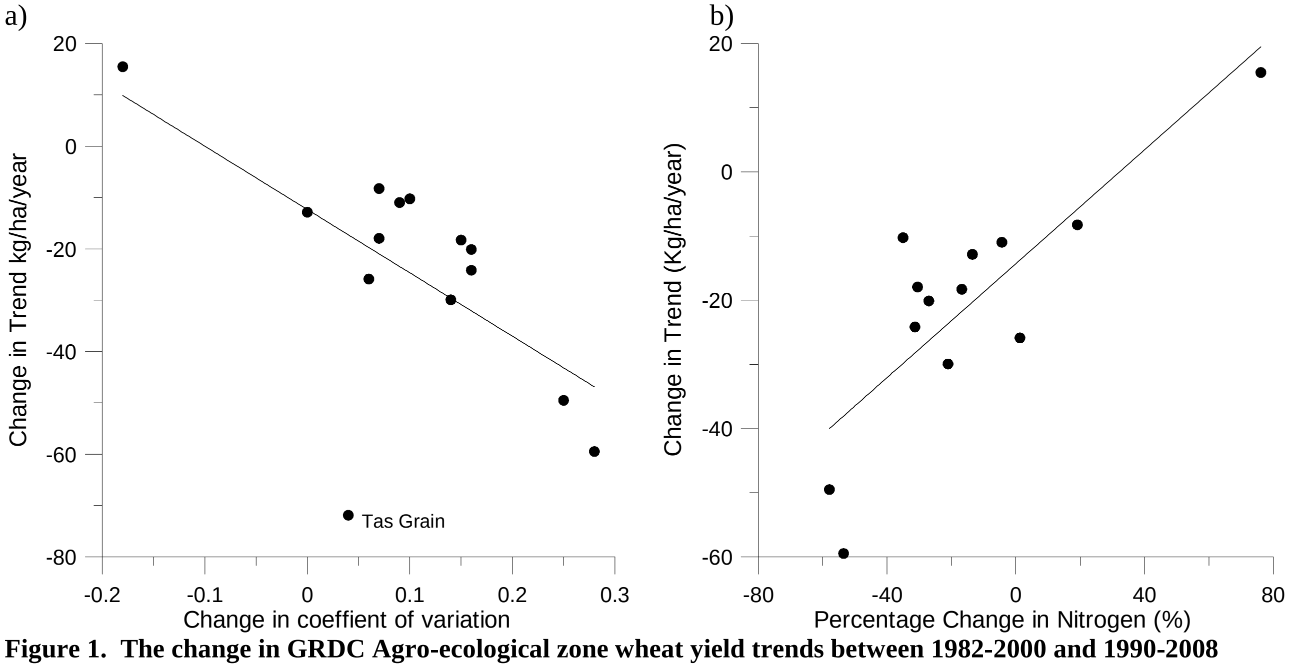

Figure 1. The change in GRDC Agro-ecological zone wheat yield trends between 1982-2000 and 1990-2008 versus: a) the change in the coefficient of variation in de-trended yields between 1982-2000 and 1994-2008 (with Tasmanian excluded, r^2 = 0.80), and b) the percentage change in nitrogen at the end of the two respective periods, i.e. 2000/01 and 2007/08 (r^2 = 0.67, note Tasmania excluded).

In Comparison to wheat, the high rate of sorghum yield increase in the 1980s and 1990s actually increased as the calibration of the Oz-Sorghum model moved forward a decade (Table 2). All trends in this case were significant (at 0.05 p-values) and only the percentage change in sorghum yields in NSW slightly decreased.

Table 2. Sorghum yield trends in kg/ha/year and percentage change per year as a ratio of the long-term average

for sorghum growing States and Australia.

Period	1982/83 to 2000/01		*1990/91 to 2008/09*	
Region	Kg/ha/yr	%/annum	*Kg/ha/yr*	%/annum
National	65.13	2.98	104	3.9
New South Wales	102.3	4.39	123	4.2
Queensland	33.83	1.64	77.3	3.2

There was less of a clear relationship between variability and sorghum yield trends as variability went up in New South Wales and decreased in Queensland. Surveys of agronomists highlighted that genetic gains from hybrid varieties and better sorghum management had lead to the large gains in yield. This was confirmed with WUE modelling analysis with Oz-Sorghum, which found very large (40-70%) increases in inland areas, and increases of the order of 10-40% in traditional sorghum growing areas. In inland areas farmers began to focus on increasing sorghum yields as sorghum became more profitable than wheat. Higher increases in WUE were found where there was a shift to wider row spacing, variable rate fertiliser and a matching of fertiliser application to soil tests.

Conclusion

The abrupt change to a drier more variable climate resulted in a strong interaction between climate and wheat technology in the four southern mainland States. We confirm the hypothesis that N fertiliser is a major driver of yield trends, but for the first time document the very important role of yield variability as a major driver of productivity changes. Overall, it appears that the very factors that underpinned record wheat yield increases in the 1990s produced a cropping system that was vulnerable to the changed climate experienced in the 2000s. High rates of nitrogenous fertilisers, early sowing and higher adoption of grain legumes and oilseeds were most affected. For sorghum climate change appears to have had much less of an impact as genetic and management gains have continued in a drier climate.

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