Risk assessment of climate change impacts on Australia's wheat industry

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Abstract

We describe a systematic risk assessment of the combined effects of possible increases in atmospheric carbon dioxide concentrations and associated temperature increases and rainfall changes on the Australian wheat industry for the year 2070. The likely impacts of these three factors varied markedly among regions, with those in Western Australia having a high likelihood of significant yield reductions, but those in north-eastern Australia having a high likelihood of moderate increases in yield but also a small probability of substantial yield reductions. Nationally, whilst median yields are little changed (without adaptation) there is a significant risk to the industry as increases in crop value are limited (to about 10% or $0.4B p.a.) but potential losses are large (about 50% or $2B p.a.). Adaptation strategies of changing planting dates and varieties could be highly effective by offsetting the negative impacts of global change and enhancing positive aspects. The median benefit of these adaptations was about $225M p.a. but with a range of $100M to over $500M p.a. Identifying further adaptation strategies and building the capacity in the farming community to implement them will be a key pathway to deal with uncertain climate and atmospheric changes in the future.

Media summary

Increases in atmospheric CO_2 and associated climate changes pose a significant risk for the Australian wheat industry. Adaptation strategies could substantially reduce this risk.

Key Words

Wheat, climate change, adaptation, Australia, risk

Introduction

Wheat is the major crop in Australia in terms of value ($4.2 billion), volume (22Mt) and area (11Mha). Yields are generally low due to low rainfall, high vapour pressure deficit and low physical and chemical soil fertility. High climate variability forces low input management to limit financial risk. Thus the Australian wheat industry is highly sensitive to climatic influences. Increases in levels of atmospheric CO_2 and other greenhouse gases are considered likely to significantly change global climate, increasing temperature and changing regional rainfall patterns, with consequent impacts on the wheat industry. However, there is considerable uncertainty in scenarios of CO_2 increase and related climate change - and wheat responds to both factors, with raised CO_2 levels enhancing crop growth through increased photosynthetic rates and water use efficiencies, but reducing grain protein content (e.g. Howden et al. 1999). Atmospheric CO_2 levels may rise from current levels (370ppm) to between 525ppm and 716ppm by the year 2070. In the same time frames, temperatures across Australia may increase by a range of 1?C to almost 7?C by the year 2070. Large changes in rainfall are possible with changes of up to ±60% by 2070 – noting that there is marked variation between regions and seasons. Such changes in climate and CO_2 levels would have potentially significant impacts on wheat yields in Australia as well as areas suitable for cropping, changes in salinity and erosion risk (e.g. Reyenga et al. 1999, van Ittersum et al. 2003).

Earlier site-based analyses of the impact of combined changes in atmospheric CO_2 concentration and regional climate change (e.g. Howden et al. 1999) did not account for the large range of uncertainty in CO_2 and climate changes nor scale this up to the national level. This study attempts to incorporate uncertainty in CO_2 levels and consequent climate changes into one analysis using Monte Carlo (random number) sampling across the specified ranges of uncertainty at each level. The output of such analyses is a probability distribution – it indicates the likelihood of different outcomes for input into risk analyses.

Method

The project focuses on ten sites in the major Australian wheat growing districts as a pathway to scaling up results for the whole of the industry. The sites were Geraldton, Wongan Hills, Kattanning, Minnippa, Horsham, Wagga Wagga, Dubbo, Moree, Dalby and Emerald. Response surfaces of mean wheat yields to CO_2, rainfall and temperature were developed for each site using I-Wheat (Meinke et al. 1998) which is a module of the APSIM systems modelling framework (Keating et al. 2003). The approach used to model CO_2 response (Reyenga et al. 1999) has been validated (Asseng et al. 2004). I-Wheat was run for a factorial combination of CO_2 increase, temperature and rainfall change using modified 100-year climate records (Reyenga et al. 1999) to provide response surfaces (or a summary model) of the general form:

Yield change (% from historical mean) = $aCO_2 + bT + cR + \varepsilon$ Equation 1

Where T (?C) and R (% change) are temperature and rainfall change respectively from the 100-year average, CO_2 is in parts per million and ε is the residual error. Most regressions had non-linear terms and interaction terms in the above equation. A separate response surface was developed for simulations which included optimised management adaptations of change in variety and change in planting window (Howden et al. 1999). Change in grain nitrogen (%) was calculated as a function of yield change using similar regression techniques. These response surfaces were sampled using Monte Carlo methods using a proprietary package (@RISK). Uncertainty in the input variables (i.e. CO_2, temperature, rainfall) for this sampling was incorporated using the following approach.

Carbon dioxide concentrations for 2070 were sampled using a uniform distribution across the range of values provided by the Intergovernmental Panel on Climate Change scenarios (525ppm to 716ppm: IPCC 2000) which relate CO_2 levels to global temperature change. For the sampled CO_2 level, global temperature change was sampled using a uniform distribution from within the range of values provided. Uniform distributions were assumed as there is no *a priori* reason for CO_2 concentrations to have a greater likelihood of occurrence at any point within this range. The global temperature changes were then used to calculate monthly temperature and rainfall changes (Figure 1) at the ten sites using probability distributions derived from the results of nine Global Climate Models (Howden and Jones 2001). Means of the monthly values across the growing season (typically May to October) were calculated to sample the response surfaces from which yield changes were subsequently calculated (Equation 1). Correlation matrices were calculated between all sites for both precipitation and temperature changes as adjacent sites are likely to have similar climate changes within a sampling whilst sites distant from each other may be largely independent (Howden and Jones 2001).

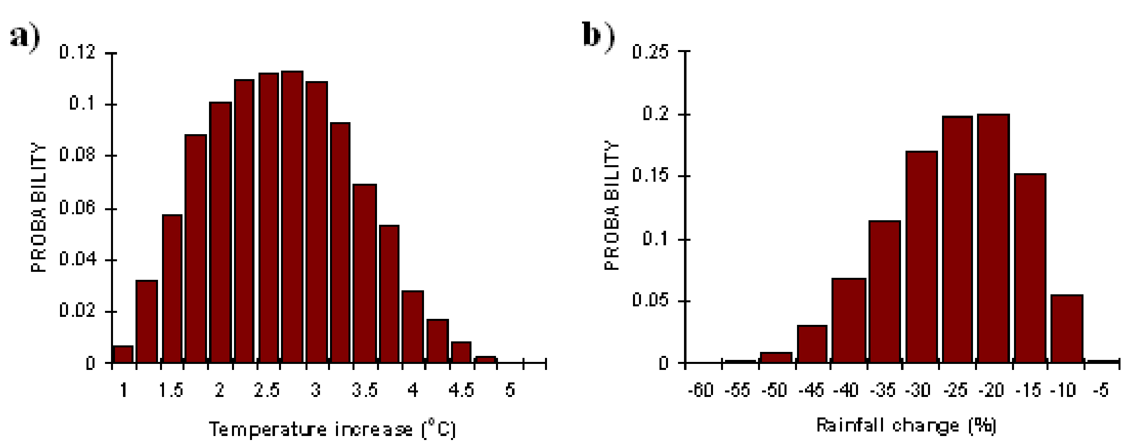

Figure 1. Change in a) temperature (?C) and b) rainfall (%) for Wongan Hills for the year 2070.

Changes in site yield (t/ha) were scaled to regional productivity (tonnes) using the average regional Australian Bureau of Statistics (ABS) production statistics for the past decade and the change in yield under a given global change scenario. These regional values were then aggregated to give national production. Crop value ($/tonne) was calculated as a function of grain N concentration (%N) based on several years' data (Howden et al. 1999):

Value ($/tonne) = $-66.395x^3+435.6x^2-851.36x+656.81$ Equation 2

Where x is calculated percent nitrogen (N%) in the grain. For simplicity, the same equation was used for all States although minor differences occur. Regional crop value was then re-calculated using the yield changes and the revised crop value and then aggregated to national values. We did not incorporate changes in cropping areas for the global change scenarios as a response of change in yield potential and risk as there may be buffering responses via landuse changes (e.g. Reyenga et al. 1999). These require further analysis.

Results

There was considerable variance in the responses among the ten sites. Wongan Hills (Western Australia) and Dalby (Queensland) were chosen to represent two extremes of response. For Wongan Hills, the climate change and CO_2 scenarios resulted in marked reductions in yield in the absence of adaptation (Figure 2a) with extreme reductions of 80%. There was a small (6%) likelihood of increased yields. Median yields were 18% lower than historical values. In contrast, for Dalby in the year 2070, there was an 82% likelihood of increases in yield (Figure 2b) with these being up to 35% higher than historical values. Nevertheless, there was significant chance of lower yields with reductions up to 42% compared with historical yields. Median yields were 12% higher than the historical baseline.

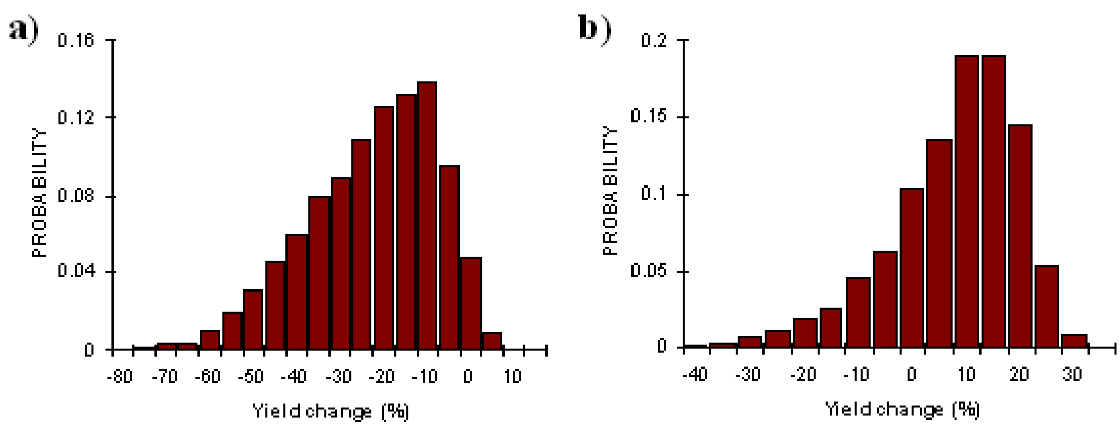

Figure 2. Changes in grain yield (%) for a) Wongan Hills (WA) and b) Dalby (Qld) in the year 2070 with no adaptations practiced.

When aggregated to a national basis, with no adaptation simulated, the yield changes in addition to changes in price associated with altered grain protein content resulted in effectively no change (-0.3% or -$15M p.a.) in median crop value (Figure 3a). However, there is a marked skewness of possible results with national gross crop value possibly falling by as much as 49% but increasing by only 10%.

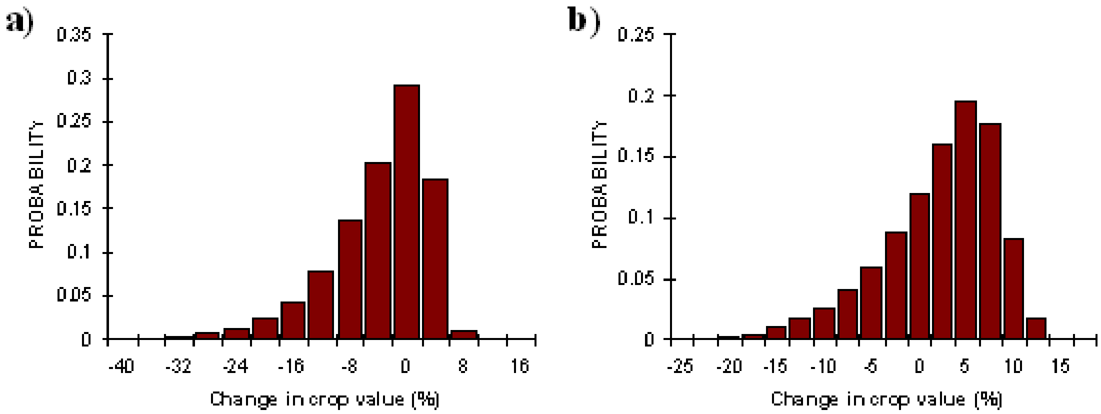

Figure 3. Change in national gross value of the wheat crop from historical baseline values (%) for the year 2070 as a result of increase in CO_2 and change in temperature and rainfall a) without adaptation and b) with adaptations of changed planting windows and varieties.

When adaptations of changing varieties and changing planting windows (to take advantage of reduced frost risk) were simulated across the Australian wheat growing industry for the year 2070, there was a marked offsetting of the negative impacts of global change and an enhancement of the positive aspects (Figure 3b), resulting in the median value the national wheat crop increasing by 5% ($190M p.a.) with a range from –25 to +16%. The value of adaptation at a national level (i.e. the difference between Figures 3b and 3a) ranged from $100M p.a. to $550M p.a. with a median of $225M.

Discussion

The approach described here allows a risk assessment of the combined effects of possible increases in atmospheric carbon dioxide concentrations, and associated temperature increases and rainfall changes on the Australian wheat industry. The approach enables a systematic treatment of the high levels of uncertainty in: 1) scenarios of global CO_2 emissions, 2) the implications of these emissions for global temperature change and 3) the implications of global temperature change for regional temperature and rainfall change in Australia. It provides indications of both the median and extreme ranges of change likely for regional and national wheat yields and crop value.

Increases in atmospheric concentration of carbon dioxide and associated climate changes are likely to have significant effects on the Australian wheat industry, impacting on yields and on gross value of production. Generally, increases in CO_2 concentrations had a significant positive impact on wheat yields and gross crop value but these effects were over-ridden in some scenarios of large reductions in rainfall and large increases in temperature, leading to significant risk to the industry at both regional and national levels. The likely impacts varied markedly among regions with regions in Western Australia having a high likelihood of significant reductions in yield, but those in north-eastern Australia having a high likelihood of moderate increases in yield but also a small probability of substantial yield reductions. At the national level, whilst median yields are little changed (without adaptation) there is a significant risk to the industry as the scope of increases in crop value is limited (to about 10% or $0.4B p.a.) but the scope of potential losses is large (about 50% or $2B p.a.)

Investment in developing adaptation strategies could be highly effective, offsetting the negative impacts of global change (particularly in the WA sites) and enhancing the positive aspects (particularly in eastern Australia). Use of these readily implemented adaptation strategies (changing planting windows and varieties) fundamentally alters the risk profile of climate change, changing the median result from a negative to a positive with a median gain of about $225M p.a. but with a range of $100M to over 500M p.a. Clearly, there is a sound investment in identifying suitable adaptation strategies and building the capacity in the farming community to implement them so as to deal with uncertain climate and atmospheric changes in the future.

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