Using Yield Prophet? to determine the likely impacts of climate change on wheat and barley production

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Abstract

Regionally specific scenarios of the likely changes in seasonal rainfall and temperature are now readily available. Yield Prophet? (www.yieldprophet.com.au) is an on-line interface for the crop production model APSIM (www.apsim.info) that now has the potential to allow individual growers to assess how climate change will impact on crop yields at the paddock level. This paper describes how climate change scenarios for 2030 were incorporated into Yield Prophet? and used to develop tools which allow users to assess; (i) whether there have been any discernable changes in crop yields in response to recent climatic changes; (ii) yield distributions under different climate change scenarios assuming current practices; and (iii) yield distributions under different climate change scenarios assuming adaptation strategies. These tools are to be used on-line to allow growers and consultants to design scenarios specific to soil type, meteorological station, crop type and cultivar, sowing date and density. This knowledge will assist in making adaptive changes in crop management to cope with seasonal variability and changes in climate.

Key Words

Climate change, Yield Prophet, wheat, barley, modelling

Introduction

Climate change is a challenge that current Australian grain farmers will have to face. Continued productivity and viability of farms will only be maintained if managers are able to adapt their systems, practices and business to changed conditions. Regionally specific scenarios of the likely changes in seasonal rainfall and temperature have in recent times become readily available through state extension publications and several interactive websites (www.csiro.au/ozclim and www.climatechangeinaustralia.gov.au). However, grain growers and their advisors currently have no means by which to assess how these scenarios will impact on crop yields, or to what extent negative effects of climate change may be mitigated by adaptation strategies.

There is also significant curiosity from farmers and advisors regarding the role of climate change in what, for many regions, has been a decade of below average rainfall. There has been no tool based on long-term meteorological data available that allows investigation of climate variability and change at a regionally specific level. This paper describes how an existing online crop simulation service (Yield Prophet?) was enabled to generate paddock specific yield simulations. These simulations allow investigation of climate change to date, crop yields under future climate change scenarios, and how adaptation strategies might mitigate the impact of climate change on yield. The aim is to provide a tool that can assist with climate change detection, planning for future change, and adaptation.

Methods

Climate change scenarios

Monthly mean climate change scenarios for the year 2030 are obtained from the OzClim website (www.csiro.au/ozclim/home.do) for the location of user defined patched point data set (PPD) met stations. IPCC climate change scenarios used for the report are A1F1 emissions using the GFDL-CM2.1 model with high climate sensitivity (‘worst case’) and B1 emissions using the NCAR:CCSM3 model with low climate sensitivity (‘best case’).

Focusing exclusively on changes in the means?ignores any changes in?dispersion.?A quantile regression estimating multiple rates of change (slopes of the 10th, 50th and 90th percentiles) of daily max & min temperature, provides a more complete picture of the?projections missed by other regression methods. In order to capture the changes in extremes of the distribution, past trends were investigated using M-quantile regressions (Breckling and Chambers 1988) for reference meteorological data sets in each region. These transformations were then applied?in conjunction?with the mean monthly temperature changes?(from IPCC scenarios above) to?historic met data for the IPCC baseline 1980-1999. The historic daily rainfall series (1980-1999) is simply adjusted by the monthly mean change. Finally, simple linear models of radiation, vapour pressure and evaporation are developed from the historical series of maximum temperature. The same model predicts these variables for the projected climates.

Input data and simulation structure

Yield Prophet? subscribers enter paddock specific information such as soil type and nearest PPD meteorological station into the Yield Prophet? website, as per regular Yield Prophet? use (Hunt *et al.* 2006). In order to generate a climate change report, the user must also provide a sowing rule, cultivar and plant density and nominate if they would like the simulation to run assuming full stubble retention, or with a percentage of stubble removed in each season. Users also have the opportunity to enter an ‘adaptation’ strategy of changed sowing rule, cultivar, plant density and stubble retention under a climate change scenario of their choosing (‘best case’, ‘worst case’ and a ‘moderate’ scenario represented by IPCC A1B emission scenarios using the Max Planck ECHAM5/MPI-OM model and medium climate sensitivity). This information is then sent from the website to the Yield Prophet? run machine that creates four one-hundred year continuous wheat simulations in APSIM (Keating *et al.* 2003), describing wheat yields for current, ‘worst case’, ‘best case’ and ‘worst case adaptation’ scenarios. The effect of an increase in atmospheric CO_2 concentration (to 420ppm for ‘best’ and 460 ppm for ‘worst’ case scenarios) and temperature on crop growth is captured in the APSIM wheat model with two functions that influence key model parameters (Radiation Use Efficiency and Transpiration Efficiency) that were derived from literature (van Ittersum *et al.* 2003). Output is graphically formatted according to the report template, and returned to the users’ online account for viewing.

Results

The climate change report graphically represents simulation output. Simulated attainable wheat yields (assuming that nitrogen is not limiting) for the last 100 years assuming user-defined ‘current’ practice are presented as a histogram with a mean and running mean (Figure 1). This puts recent seasons in the context of annual and decadal variability for the past century.

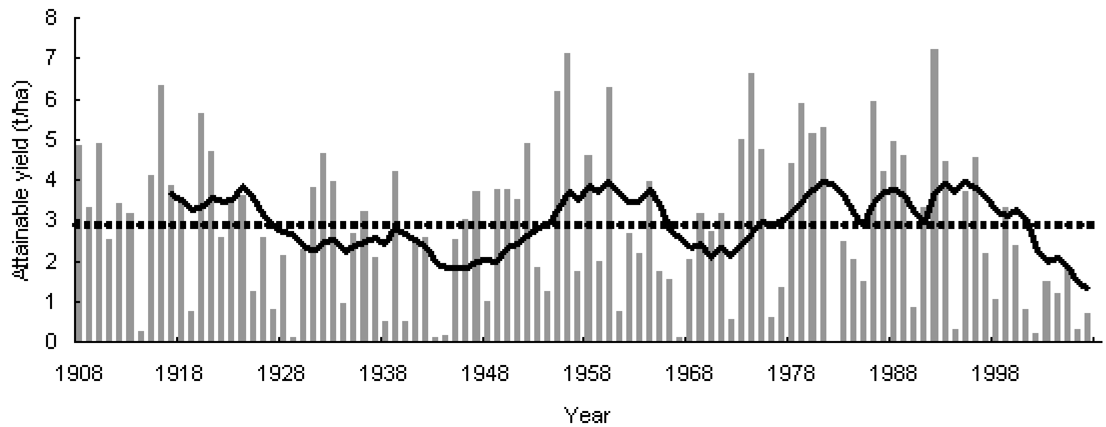

Figure 1. Simulated attainable wheat yields from 1908 to 2007 for a hypothetical paddock at Birchip, in north-west Victoria (■), mean attainable yield (????) and 10 year rolling mean (▬).

Probability of exceedence (probability that a given yield will be exceeded) graphs for the last thirty years and all other years (Figure 2a) and the last ten years and all other years (Figure 2b) provide a simple means for climate change detection. A Kruskal-Wallis test is used to determine if the distributions of recent and all other years are significantly different at a 90% confidence level.

a) **b)**

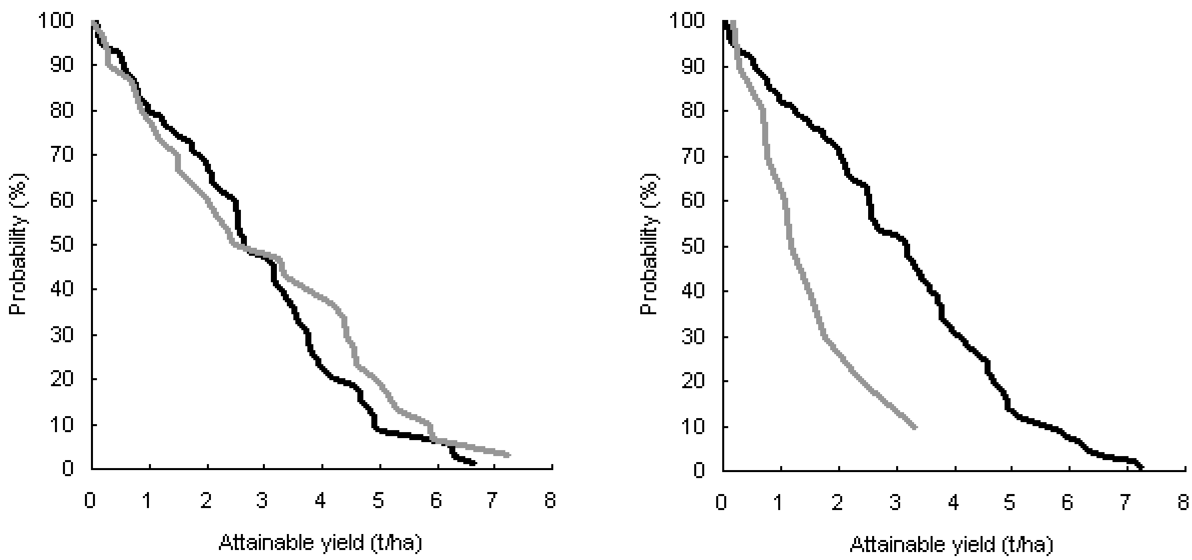

Figure 2. a) simulated attainable wheat yields from 1908-1977 (▬) and 1978-2007 (▬) at Birchip, there is no significant difference between the distributions (p=0.62). b) simulated attainable wheat yields from 1908-1997 (▬) and 1998-2007 (▬) at Birchip, there is a significant difference between the distributions (p=0.01).

Probability of exceedence is also used to represent yield outcomes for ‘best case’ and ‘worst case’ scenarios relative to baseline years 1980-1999 assuming current practice (Figure 3), and adaptation (Figure 4).

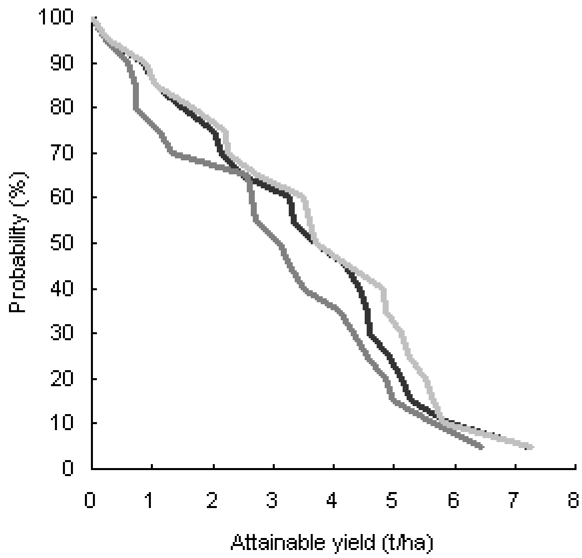

Figure 3. Simulated attainable wheat yield for 1980-1999 for Birchip (—), and for the same period under ‘worst case’ (—) and ‘best case’ (—) climate change scenarios.

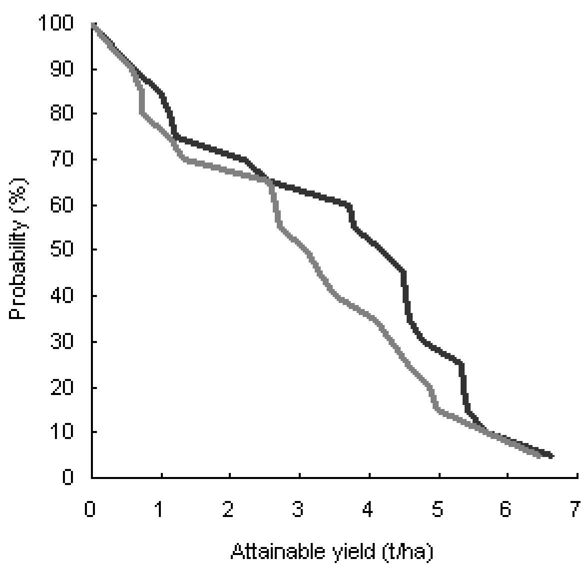

Figure 4. Simulated attainable wheat yield for 1980-1999 for Birchip under ‘worst case’ climate change scenarios assuming current practice (—), and ‘worst case’ assuming complete stubble retention and earlier sowing window (—) as adaptation strategies.

Conclusion

The information presented in Figs 1-4 provide growers and consultants with a means to detect occurrence of climate change, and an estimate of how current IPCC climate change scenarios for 2030 will affect productivity on their farm. In the example above, change in attainable wheat yields at Birchip has been detected. Ten year rolling mean yield is currently lower than it has been at anytime in the last 100 years (Figure 1), and attainable wheat yields from 1998-2007 are significantly lower ($P<0.1$) than those from 1908-1997 (Figure 2). This section of the report makes no inference about future climate, or attribution of detected change to any possible cause (e.g. inherent variability or global warming caused by human activity).

Simulation indicates that yields under worst case climate change scenarios could be improved by farming systems adaptation, in this example through adoption of full stubble retention and taking advantage of earlier sowing opportunities (Figure 4). Growers and advisors can use this information to assist with strategic decisions such as succession planning, acquisition of new land etc, as well as in tactical applications including farming systems adaptation and design. There are numerous 'missing links' and caveats associated with the Yield Prophet? Climate Change Report which will need to be communicated to users. These include a possible increase in the frequency of frost and heat shock events under climate change, increased drought intensity and a decrease in magnitude, frequency or altered timing of seasonal breaks. All of these have serious implications for crop yields and are not considered in these simulations. It also overlooks the possibility that the last decade may be a 'step' function of climate change, and that the 1980-1999 climate baseline is no longer a valid benchmark over which to impose change. In spite of these limitations, the report provides what is to-date the only easily accessible means for grain growers to assess how climate change scenarios will impact on crop yields.

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