Future Climate and Wheat Yields in Western Australia

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Climate change projections for the mid 21st century for southern WA indicate an increase in temperatures, a decrease in growing season rainfall and higher CO_2 concentrations. These changes could have adverse impacts on some agricultural systems, but they may also offer new opportunities.

We studied potential impacts of climate change on wheat production by combining three modelling systems. Daily climate data for current and future conditions from the CCAM global climate model was statistically downscaled to individual locations in the WA wheatbelt. This climate data was then input to the APSIM-Wheat simulation model to evaluate wheat yield and phenology under current and future climate for several typical soil types. The aim was to investigate the usefulness of such a modelling cascade in defining key risks to wheat cropping from projected climate change, and here to provide a template for possible responses by barley.

In an earlier stage of the project, we compared climate simulation from several GCMs (CSIRO Mk3, CCAM, ECHAM and HADCM), and selected the CCAM model as best representing the climate of southern WA. This was used for a more detailed study of the impacts on wheat cropping. The APSIM model simulates crop development, growth, yield, water uptake and nitrogen accumulation in response to temperature, radiation, day length, CO_2 level, soil water and nitrogen supply. It offers a framework for investigating interactions and testing some simple adaptation options.

The CCAM model simulated total annual rainfall reductions of 5-11% for 2050 across the locations studied (consistent with other model projections). Total annual rainfall reductions tended to be higher in the high-rainfall areas than in the low or medium rainfall sites. The highest seasonal rainfall reduction was predicted for April-June, resulting in later sowing opportunities and decreasing expected yields.

The impacts of climate change varied depending on the location and soil type. In most locations the positive impact of increased CO_2 levels was more than offset by the negative effect of lower rainfall, delayed sowing and increased temperatures. The impact on yields was greatest on clay soils. Yield reductions are expected in most locations, but there could be opportunities for increased yield in some high-rainfall locations due to reduced waterlogging. These results are closely matched by those of a related study on changes to land suitability for barely that used a different modelling methodology. This suggests a similarity and robustness in response to climate.

Adaptation to likely future climate will clearly be needed to both mitigate risk in drier regions and to take opportunities in wetter regions. Options such as changing fertiliser management and cultivar choice could be effective, but will need testing in a wider agricultural systems context. Changed seasonal variability and yield distributions will place more emphasis on the need for improved management of climate variability in the future. The likelihood of varying regional yield responses offers both challenges to maintain variability, and opportunities for cropping in new areas.

Keywords:
Climate change modeling, APSIM Wheat model, rainfall

Aims:

Climate change projections for the mid 21st century for southern WA indicate an increase in temperatures, a decrease in rainfall and higher CO_2 concentrations. These changes could have adverse impacts on some agricultural systems, but they may also offer new opportunities (i.e. in areas where the risk of waterlogging may be reduced). The aim of this paper is to quantify the impact of climate change on the wheat production in the wheatbelt of WA. Downscaled climate data from a CSIRO Global Climate Model (GCM) was used as input into the APSIM-Wheat simulation model, in order to evaluate the wheat yields under future climate in a range of representative locations and soil types of the West Australian Wheatbelt

Method:

The Cubic Conformic model (CCAM), which is a higher-resolution variant of the CSIRO GCM MK3 model, was downscaled to provide daily climate data for current (1976-2005) and future (2035-2064) periods for different locations in the West Australian wheatbelt. Differences in future and current simulated rainfall was assessed in terms of monthly rainfall.

The APSIM-Wheat model was run with current and future climate data to simulate grain yield. The wheat model was run with two sets of climate data for 30 year periods: 1) current simulated climate for the period 1976-2005 with current level of CO_2 (350 ppm) and 2) future simulated climate for the period 2035-2064 with expected CO_2 level in the mid 21st century (440 ppm).

The APSIM-Wheat model simulates crop development (phenology), growth, yield, water uptake and nitrogen accumulation in response to temperature, radiation, daylength, soil water and nitrogen supply. The model uses a daily time-step and is driven by daily weather inputs. It calculates the water-limited potential yield of the site, that is, the yield not limited by weeds, pests, and diseases, but limited only by temperature, solar radiation, water, and nitrogen supply at that site.

Simulations were run for eight representative locations and three soil types of the WA wheatbelt. The locations were chosen to represent the range of rainfall zones (high, medium and low) and agricultural regions (north, central and south) present in the wheatbelt of WA (Table 1). Three typical soil types of the area, a sandy soil, a duplex soil and a clay soil, with 59, 86 and 116 mm plant-available water, respectively, were chosen. Waterlogging effects on crop growth and yield were accounted for on the duplex soil. Simulations were performed for periods of 30 years assuming the soil was dry at 1st January each year. Sowing time was controlled by a sowing rule. Every year sowing occurred in the first sowing opportunity between 25th April and 31st July. A long season cultivar was sown if sowing occurred before 20th May, a medium season cultivar was sown between 21st May and 9th June, and a short season cultivar was sown after that date. Current management in the area was selected for the simulations.

In a related study Vernon and Van Gool (2006) used land use capability data and current climate information for the agricultural zone of Western Australia, combined with a modified French and Schultz equation to produce a potential yield map for barley. Another yield map was then produced for 2050 based on SRES marker scenario A2, using mean seasonal rainfall from the CSIRO Mark 2 global climate model. This approach used gridded mean climate data that provided good spatial coverage while trading off interannual variability information.

Table 1. Selected locations, latitude, longitude, rainfall zone, agricultural region, average annual rainfall for the period 1976-2005 and 2035-2064.

Location	Annual rainfall 1976-2005	Annual rainfall 2035-2064	% change
Merredin	353	329	-7
Badgingarra	576	524	-9
Dalwallinu	386	355	-8
Corrigin	389	368	-5
Wandering	597	534	-11
Lake Grace	367	336	-8
Wagin	462	413	-11
Esperance	664	622	-6

Results:

The climate model used in this study simulated annual rainfall reductions of 5 to 11% across the 8 locations studied for the period 2035-2064 compared to the period 1976-2005 (Table 1). Total annual rainfall reductions tended to be higher in the high rainfall locations than in the low or medium rainfall locations. In terms of rainfall distribution, the model simulated a small increase in summer rainfall (0 to 20% increase in rainfall in January to March period, Fig. 1). April to October rainfall is simulated to decrease in the future for all locations. The greatest rainfall reductions are simulated to occur in the period April to June (0 to 30 % reduction). Some of this decrease appears to come from a seasonal bias within the CCAM simulation of WA climate, and some of it comes from atmospheric response to higher CO_2 concentrations.

Given that the amounts of summer rainfall are usually small and highly variable, the increase in summer rainfall may have only a small contribution to higher stored soil water at sowing. The decrease in autumn rainfall will result in late sowing opportunities and therefore reduced expected yields. The decrease in April to October rainfall will result in increased crop water deficit, especially where water is already a limiting factor. The decrease in growing season rainfall will be positive in locations and soil types where excess water is currently causing waterlogging problems.

The impact of future climate expressed as percentage yield difference showed yield decline in most locations (Fig. 2). However, there was a less than 5% increase in yields in Corrigin on the sandy and duplex soil and a 6% yield increase in Esperance on the duplex soil. Future yields increased on all three soil types in Wandering. Yield decline was in the range 10-13% on the clay soil in 6 locations. On the sandy and duplex soils yield decline ranged from 2 to 8%. The crop model simulated the effects of waterlogging on crop growth and yield on the duplex soil. In Corrigin, Esperance and Wandering yields increased in the future on the duplex soil, as a consequence of the reduction of the detrimental impact of waterlogging in the future. Among soil types, yield reductions were greater on the clay soil than on the sandy or duplex soils.

The yield decrease was due to lower rainfall and higher temperatures, which caused shorter growth duration and more water deficit in most locations. The lower rainfall in autumn caused delayed sowing, which caused a reduction in growth duration and increased chance of a more severe water deficit during grain filling. In most locations, the positive effect of increased CO_2 levels was more than offset by the negative effect of lower rainfall, delayed sowing and increased temperatures.
The yield increase in some high and medium rainfall locations was due to the positive effect of increased CO_2 levels and reduction of waterlogging effects.

These reductions in potential wheat are similar to those predicted for barley by Vernon and van Gool (2006). Their modelling indicated that an extensive area encompassing much of the eastern, central, southern and south-eastern wheatbelt may experience a 10-30 per cent yield reduction by 2050, mainly due to reduced seasonal rainfall. Of the major barley growing areas, Lake Grace was significant as having a both a high total reduction (>10,000 tonnes) and an 11 per cent reduction in yield potential. However, little change was indicated in the western area of the agricultural zone (greater than 350 mm annual rainfall).

Figure 1. Percentage difference between future (2035-2064) and current (1976-2004) monthly rainfall for 8 locations in the West Australian wheatbelt. Rainfall obtained from downscaled CCAM model.

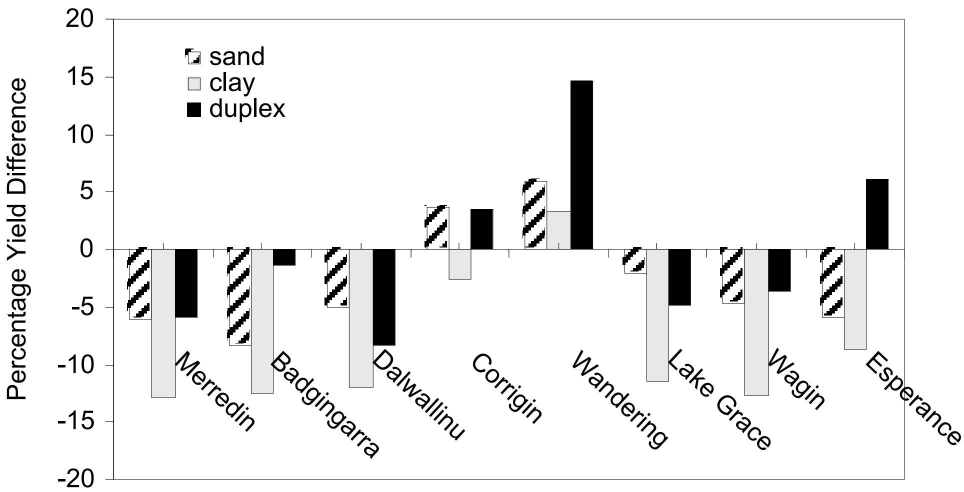

Figure 2. . Impact of future climate on yield expressed as percentage yield difference between future and current simulated yields for 8 locations and 3 soil types. Simulated climate obtained from the CSIRO CCAM model. Simulated yields with APSIM-Wheat model

Conclusions:

Simulations of future climate indicate a consistent decrease in growing season rainfall for most sites in the WA wheatbelt. Projections of summer rainfall changes are more uncertain and variable.

Prospects for future yields show a consistent decline in the low rainfall zones and a yield increase in some high rainfall locations and waterlogging prone soils. Heavier soil types (i.e. clay soil) are more vulnerable to climate change than light textured sandy soils. Increased CO_2 concentration offers benefits to the crop, but does not fully compensate for decreased rainfall in low rainfall areas.

Adaptation will be needed to overcome some of the projected adverse impacts of climate change. Adjusting farm management (i.e. fertilizer management, cultivar choice) may counteract some the negative impacts of climate change. One key component will be improved management of seasonal variability. This study has shown a shift to later sowing dates and a yield distribution that includes more frequent lower-yielding years in medium to low rainfall locations. Such an environment will require management that is closely matched to season type.

The yield responses shown here for wheat are similar to those estimated by Vernon and van Gool (2006) using a different modelling methodology. Both studies also indicate similar spatial patterns of response – indicating regions of potentially improved yields in the future. The clear challenge for cropping adaptation is in low rainfall areas. Our study has assumed no change to current cropping practices, so investigation of the capacity for adaptation is an area for future work.

References:

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