Likely impact of climate change on wheat and sorghum production in central Queensland

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Abstract

We investigated the impact of four climate change scenarios derived from the CSIRO Mk3 Global Circulation Model on wheat and sorghum production for the shires of Emerald and Banana in central Queensland using shire-scale simulation models. Simulated wheat and sorghum yields for these scenarios were compared with current climate for the years 2030 and 2070. The four scenarios involved temperature increases of 0.3 and 1.9^{o} C combined with rainfall changes of -13% and +7%. The study indicated that a large decline in yield was likely under the most extreme scenario of higher temperature combined with lower rainfall; the decline was greater in wheat than in sorghum, and greater in the Banana shire. One challenge for the grain industry (including government and scientific agencies) is to anticipate these impacts and develop an R&D strategy that will allow the continuation of a profitable and sustainable cropping industry.

Media summary

Substantial reductions in yields of wheat and sorghum in Queensland are possible under projected hotter and drier conditions of climate change in the next 70 years. Mitigation and adaptation strategies should be investigated.

Key words

Climate change, agro-climatic model, stress index, simulated shire scale yield.

Introduction

Models of projected climate change scenarios based on changes in atmospheric CO_2 indicate that north-eastern Australia is likely to get hotter and drier (Whetton, 2003). This includes an important cropping area in Queensland. Although there are considerable uncertainties about the precise changes, it is worth seeing how a range of possible scenarios could affect crop yields and sustainability in order for the grain industry to adapt to these changes. Our general approach to investigate this was to determine the likely impact of four climate change scenarios on wheat and sorghum production in two shires in central Queensland. This was achieved by comparing the modelled shire crop yields with those expected under the current climate.

Methods

This is a preliminary study at a broad regional scale and the method is not suited to a detailed assessment of management options at the farm level because it does not account for the effect of CO_2 fertilisation, nor does it consider possible impacts due to a reduction in frost risk. Such specific issues need to be addressed at the field rather than shire level and require a more detailed simulation approach via a modelling platform that accounts specifically for management environment interactions. For simplicity and to assess the broad impact at a regional scale the climate change scenarios were applied to 110-year cropping sequences of wheat and sorghum monoculture.

Crop modelling

The general approach was based on a regional commodity forecasting system (Potgieter et al. 2003) with a shire-based simulation capability for wheat and sorghum. The method was applied to case studies for wheat and sorghum yields for the shires of Banana and Emerald in central Queensland. These shires were selected to assess the possible existence of a production gradient across this cropping region. Two shire-level crop models were used to generate a Stress Index (SI) for wheat (Potgieter et al. 2002) and sorghum (Potgieter et al., unpublished data). Both models incorporate daily rainfall and temperatures from fallow through to crop maturity in a simple, weekly soil water balance to determine the degree of water stress experienced by the specific crop. To account for temperature effects on wheat yield, the weekly crop water use was adjusted according to the ratio of average total evaporation during May to October (crop growth period) relative to the total evaporation of the current climate during the same period for each climate change scenario. No adjustment was needed for the sorghum model because calculated crop stress index values already incorporated temperature.

The SI values were simulated for selected climate stations in each shire and aggregated to a shire scale. The SI values were then calibrated by linear regression against shire wheat and sorghum yields obtained from the Australian Bureau of Statistics for the period 1975 to 1993 (wheat) and 1983 to 1997 (sorghum) with assumed 1990 technology. Yield distributions based on modified historical climate data (110 years) were created from the regression equations for each climate change scenario and compared with those calculated using the current climate (CC, as outlined below).

Climate change scenarios

Climate change scenarios were based on output from the CSIRO Mk3 Global Circulation Model (source: Natural Resources, Mines & Energy, Queensland). Yield changes were assessed for the years 2030 and 2070. Temperature (T) and rainfall (R) projections were combined to form four scenarios that consisted of T-lower/R-lower (LL), T-lower/R-upper (LU), T-upper/R-lower (UL) and T-upper/R-upper (UU) (Table 1). For example, if the projection of rainfall change was -13% for 2030 then a -13% change was applied to the entire rainfall record of 110 years. Required changes to historical temperature, evaporation, radiation, and vapour pressure values were calculated from the fitted regression between maximum temperature and each of the other climate variables from the baseline (current climate) data set defined as the period from 1960 to 1990 (Whetton, 2003). The “worst case” scenario for north-eastern Australia is an increase in temperature and a decrease of precipitation (i.e. the UL scenario in this study).

Table 1. Projected upper and lower limits to changes in average temperature and rainfall for the years 2030 and 2070

Year	Lower temp. (^{o}C)	Upper temp. (^{o}C)	Lower rain (%)	Upper rain (%)
2030	+0.3	+1.9	-13	+7
2070	+0.9	+5.7	-40	+20

Results and discussion

Sorghum case study

For 2030 (Fig. 1 (a) and (b)), small shifts in sorghum yields due to climate change were evident for the Banana and Emerald shires; these shifts increased considerably for 2070 in both shires (Fig. 1 (c) and (d)). In both cases the LU and UU scenarios produced yields very close to those for current climate, whereas the LL and UL (the “worst case” scenario) showed the largest shifts. In most cases there were some years when simulated sorghum yields reached the maximum simulated sorghum shire yield (vertical lines at point of highest yield, Fig. 1), because water stress did not limit production. We are currently investigating whether this asymptotic yield is an artefact of the model or a consequence of a lack of management adaptation to changed conditions (e.g. sowing dates, cultivars etc.).

For 2030 median sorghum yields for the UL scenario decrease by 7% and 4% for the Emerald and Banana shires respectively from the current climate, and even further to -41% and -33% respectively for 2070 (Table 2). The 10% percentiles in 2070 differ moderately in 2070 (–72% and –57%) as do the 90% (+25% and +3% respectively).

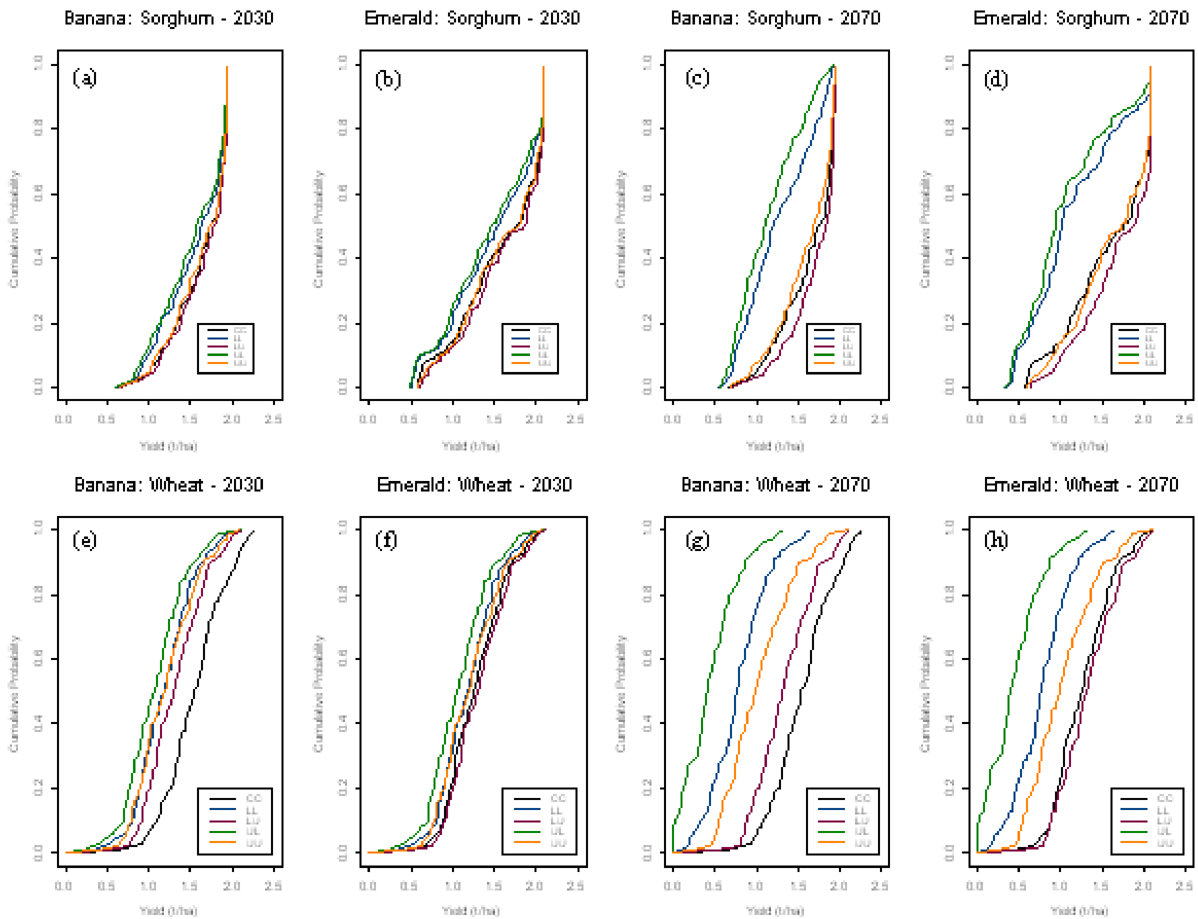

Fig. 1. Cumulative probability distributions for yields of simulated sorghum (top row) and wheat (bottom row) in the Banana and Emerald shires for the four climate scenarios: LL (blue), UL (green), LU (red), UU (orange) and CC (current climate, black).

Wheat case study

The impact of climate change on wheat yields was considerably larger than for sorghum (Fig. 1 (e) and (f)). The UL scenario produced the largest shift in yields from current climate, with all four scenarios showing significant reductions. There was also a slight decrease in the optimum yield in the Banana shire, and more failed crops in the UL scenario for both shires. This reflects the increase in water stress due to higher temperatures and lower rainfall. Shire differences in the UL scenario were larger for wheat than for sorghum. For 2030, median wheat yields decrease by 16% and 31% for Emerald and Banana from the current climate median respectively. However, wheat yields decline for 2070 by 68% and 73% for the two shires respectively (Fig. 1 (g) and (h), Table 2).

Although a more detailed modelling approach is needed to determine the likely impact of climate change on management-environment interactions, the shire scale approach used in this study provides a good assessment of the likely shifts in production that can be expected under the various climate change scenarios at a regional scale in north-eastern Australia. No significant differences were evident in sorghum yield scenarios between the Banana and Emerald shires.

Table 2. Percentage shift in simulated sorghum and wheat yields in Emerald and Banana shires for each climate change scenario, compared with those for current climate. UL is the worst-case scenario for these crops.

	Scenarios							
	LL	LU	UL	UU	LL	LU	UL	UU
	Emerald				Banana			
Percent of years	Change in yield (%)							
2030 sorghum								
10	-60	-44	-62	-46	-40	-29	-42	-33
50	-3	17	**-7**	12	0	9	**-4**	7
90	31	31	31	31	18	19	18	19
2070 sorghum								
10	-71	-35	-72	-43	-55	-22	-57	-34
50	-36	18	**-41**	10	-26	12	**-33**	3
90	29	31	25	31	12	19	3	18
2030 wheat								
10	-37	-28	-45	-38	-48	-41	-55	-49
50	-7	2	**-16**	-6	-23	-16	**-31**	-23
90	30	36	20	31	7	12	-1	8

2070 wheat								
10	-74	-30	-98	-57	-78	-42	-98	-65
50	-40	4	**-68**	-22	-50	-14	**-73**	-36
90	-4	41	-31	18	-21	16	-43	-2

Conclusion

In the absence of any adaptation or mitigation strategies, impacts of climate change on crop yields are likely to be considerable by 2030 and even greater by 2070. The challenge for industry is to anticipate these impacts and develop an R&D strategy that will allow the continuation of a profitable and sustainable cropping industry in central Queensland. This will require regional adaptation strategies (e.g. management practices such as water conservation measures, adjusting planting dates, crop choice) as well as the development of improved drought resistant and more water efficient crop cultivars which can mitigate the likely impact of climate change. Further simulation studies are needed to investigate more detailed management options at the field and farm scale to determine individual adaptation strategies as well as the integration of such tools into crop breeding programs to rapidly incorporate drought resistance into new cultivars.

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