Global Change Impacts on Wheat Production along an Environmental Gradient in South Australia.

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Abstract Crop production is likely to change in the future as a result of global changes in CO_2 levels in the atmosphere and climate. APSIM, a cropping system model, was used to investigate the potential impact of these changes on the distribution of cropping along an environmental transect in South Australia. The effects of several global change scenarios were studied, including: 1) historical climate and CO_2 levels; 2) historic climate with elevated CO_2 (700 ppm), 3) warmer climate (+2.4°C) + 700 ppm CO_2; 4) drier climate (-15% summer, -20% winter rainfall) + 2.4°C + 700 ppm CO_2; 5) wetter climate (+10% summer rainfall) + 2.4°C +700 ppm CO_2; and 6) most likely climate changes (+1.8°C, -8% annual rainfall) +700 ppm CO_2. Based on an analysis of the current cropping boundary a criteria of 1t/ha was used to assess potential changes in the boundary under global change. Under most scenarios, the cropping boundary moved northwards with a further 240,000 ha potentially being available for cropping. The exception was the reduced rainfall scenario (4) which resulted in a small retreat of cropping from its current extent. However, the impact of this scenario may only be small (in the order of 10-20,000 ha reduction in cropping area). Increases in CO_2 levels over the current climate record have not resulted in significant increases in simulated yields. Model limitations are discussed

1. INTRODUCTION

The regions used for wheat production in inland Australia are broadly limited by a combination of aridity on the inland boundaries, temperature on the northern boundaries and suitable soil types. Historical experience has resulted in the establishment of general cropping boundaries along environmental gradients. Opportunistic cropping occurs beyond these boundaries.

The distribution of wheat cropping in South Australia has a well documented history of expansion and contraction along the margins. Following settlement of the colony in 1836 there was a period of rapid expansion of agriculture northwards. After the severe drought during 1863-1866 the Surveyor-General Goyder established a line of rainfall, which marked areas of reliable and unreliable annual rainfall and beyond which cropping should not be permitted (Figure 1). However, by the early 1870's the government was persuaded by good seasons and scarce cropping lands to allow farmers to move beyond Goyder's Line (Meinig 1962). Expansion peaked in 1882 with cropping extending as far north as Hawker.

Poor seasons in the 1880's and 1890's saw the retreat of farmers back towards the Goyder's Line, forfeiting or surrendering their land selections (Meinig 1962). Cropping continued beyond the Goyder's Line with favourable seasons from 1906-1926. However, the long run of dry seasons in the 1930's lead to a second significant retreat with many farms abandoned (French 1993). Agricultural statistics show that in recent years farmers have once again begun cropping to the north of Goyder's Line.

Future change in atmospheric carbon dioxide (CO_2) levels and climate is likely to alter the potential distribution of cropping. Increasing CO_2 affects crop growth directly through the stimulation of photosythesis (Cure and Acock 1996) and improved water use efficiency (Morison and Gifford 1984) and indirectly through its interaction with other greenhouse gases which may induce climate changes (Houghton *et al.* 1996).

The aim of this paper is to use a simulation model of wheat cropping to establish criteria that relate to the position of Goyder's Line so that we can develop scenarios of cropping areas under global change. We do this by analysing simulated yields across a transect.

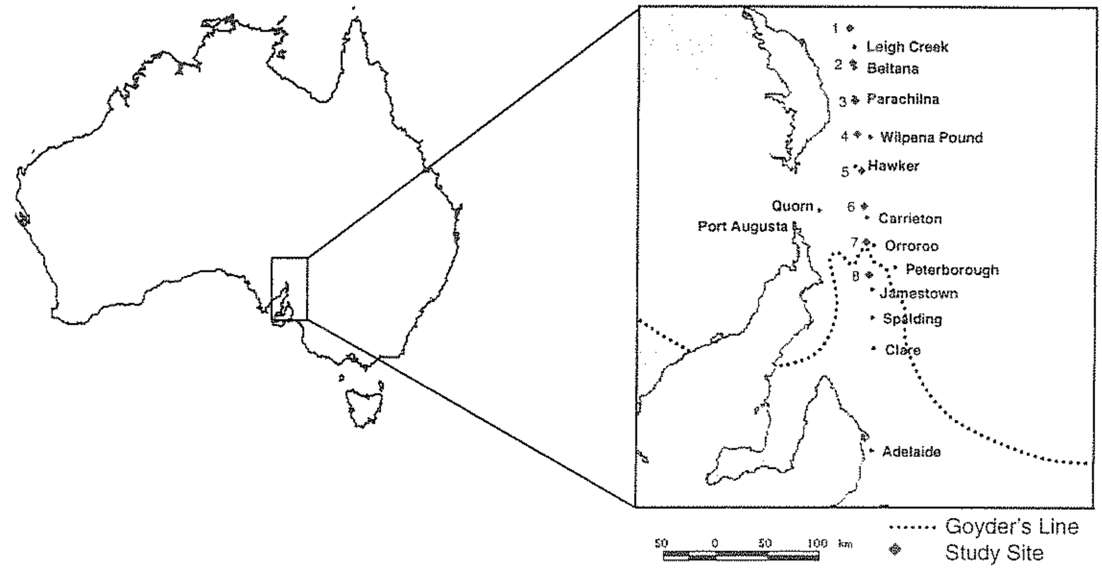


Figure 1: Location of study area

2. METHODS

2.1 Description of Study Area

The study area is a 250km north-south transect from near Jamestown (average rainfall 467 mm) to Leigh Creek homestead (average rainfall 219 mm) in South Australia (Figure 1). The approximate location and soil type of each site along the transect are described in Table 1. Soil types were based on those described in the Atlas of Australian Resources - Soils (DNM 1980), with more detailed characteristics based on soil pit data from the region (data not presented).

Orroroo (site 7), which roughly corresponds with Goyder's Line is an important cropping area with about 20,000 ha sown annually to wheat. Limited cropping currently occurs north of Goyder's Line with about 3500 ha sown to wheat in the Carrieton area (south of site 6). A small amount (~300 ha) of cropping is possible further north on red duplex soils in the Hawker region (site 5) due to the slightly higher rainfall associated with the Flinders Ranges.

Table 1: Approximate location and general soil type for each site along the transect.

	Site	Soil Type
1.	Leigh Creek	Shallow loam
2.	Beltana	Shallow loam
3.	Parachilna	Shallow loam
4.	Wilpena Pound	Shallow loam
5.	Hawker	Shallow loam
6.	Carrieton	Red duplex
7.	Orroroo	Red duplex
8	Jamestown	Red duplex

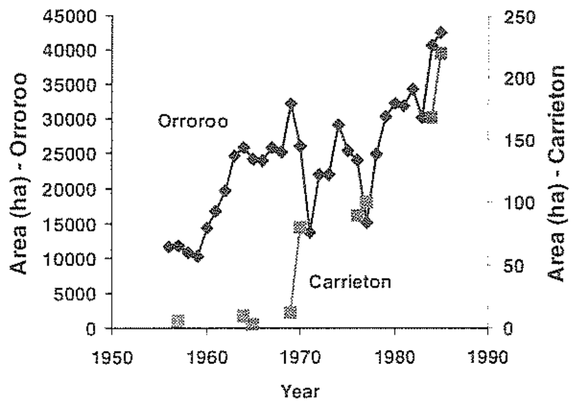
2.2 Developing Boundary Criteria

To assess the impact of global change on the distribution of cropping across the transect we developed criteria to determine cropping boundaries. These are largely determined by biophysical characteristics, which in turn affect the economic viability of cropping. Climate and soil characteristics determine average yields and the frequency of failed sowings. These are important because farmers need to achieve certain 'economic' yields to remain viable and failed sowings represent outlays with no return. The viability of a region could be also be determined by the probability of achieving a certain threshold yield (ie. 1t/ha). It is also possible that a sequence of bad years (as shown by the 5 and 10 year means) will limit development of the industry in a region. We analyse these different criteria for their suitability as indicators of current and future cropping boundaries.

2.3 Historic Increases in CO_2

Between 1890 and 1998 CO_2 levels in the atmosphere have increased from 292 to 366 ppm (Houghton *et al.* 1996). It is possible that these changes have already had an effect on yields. The historic ABS data show an expansion in the area of cropping along the current boundary (Figure 2). To assess whether this expansion was due to changes in climatic factors or CO_2, we compared simulated wheat yields with both recorded and constant (350ppm) CO_2.

Figure 2: Area (ha) of wheat cropping in the Orroroo and Carrieton SLA's.



2.4 Model Description

The wheat module, I_WHEAT (Meinke et al. 1998) from the APSIM cropping systems model (McCown et al. 1996) was used to investigate wheat yields and the impacts of global change. Briefly, leaf area and tiller formation are calculated from thermal time and phyllochron interval. Dry matter accumulation is calculated either from the amount of intercepted radiation and radiation use efficiency (RUE) or from the amount of water transpired and transpiration efficiency (TE), depending on the most limiting resource. Yield is simulated using a linear increase in harvest index (HI) with thermal time. The increase in HI ceases when nitrogen and water limitations occur. Nitrogen limitation first reduces leaf area development and then affects RUE as it becomes more severe. The degree of limitation is a function of the specific leaf nitrogen. Critical nitrogen concentrations (CNC), which vary with phenological stage, determine the nitrogen allocation within the plant. Water or nitrogen limitations result in reduced leaf expansion, accelerated leaf senescence or tiller death. To include the crop response to changes in atmospheric CO_2 concentrations, RUE, TE, specific leaf area and CNC are modified (Reyenga *e. al.* 1999).

2.5 Simulation Scenarios

I_WHEAT is a daily timestep model, which uses daily climate as input data. As there were no readily accessible long-term climate records for the transect, the climate record for the sites was generated by using interpolated daily climate surfaces (Carter *et al.* 1996).

Interactions of elevated CO_2 and climate change on wheat production were investigated using six climate scenarios (Table 2); (1) historical climate and CO_2 levels; (2) historic climate with elevated CO_2 (700 ppm), (3) warmer climate (+2.4°C) + 700 ppm CO_2; (4) drier climate (-15% summer, -20% winter rainfall) + 2.4°C + 700 ppm CO_2; (5) wetter climate (+10% summer rainfall) + 2.4°C +700 ppm CO_2; and (6) most likely climate changes (+1.8°C, -8% annual rainfall) +700 ppm CO_2 as estimated by probabilistic analysis (Jones 1998).

The global change scenarios used for this study (Table 2), were based on the CSIRO 1996 climate change scenarios assuming mid-range emissions projections and mid-range climate sensitivities for doubling of CO_2 in about 2100. Changes in temperature were added to both maximum and minimum temperatures and no changes were made to the frequency of rainfall days, so rainfall was modified by the proportion defined by the scenarios.

2.6 Planting Rules

Simulated sowing can occur within the given planting window (20 April – 10 July) the day after there has been 10 mm of rainfall. The seeds are sown at a density of 100 plants/m^2 at a depth of50mm with 60 kg/ha of NO_3-N fertiliser. A summer fallow is simulated with the water balance carried through the entire run. These rules are in accordance with local practice. The nitrogen levels were re-initialised each year as simulating nitrogen rundown or buildup was not feasible in a study of this type.

Table 2: Changes in carbon dioxide levels, temperature and summer and winter rainfall for each global change scenario

Scenario	CO2 level (ppm)	Temperature (°C)	Summer rainfall (%)	Winter rainfall (%)
Baseline	Historic (292-366)	0	0	0
CO_2	700	0	0	0
WARM	700	2.4	0	0
DRY	700	2.4	-15	-20
WET	700	2.4	10	0
MOST LIKELY	700	1.8	-8	-8

3. RESULTS

3.1 Developing Boundary Criteria

There was distinct step function in mean yields along the transect (Figure 3). North of site 6 (Carrieton), the current limit of cropping, all sites averaged yields of less than 1t/ha.

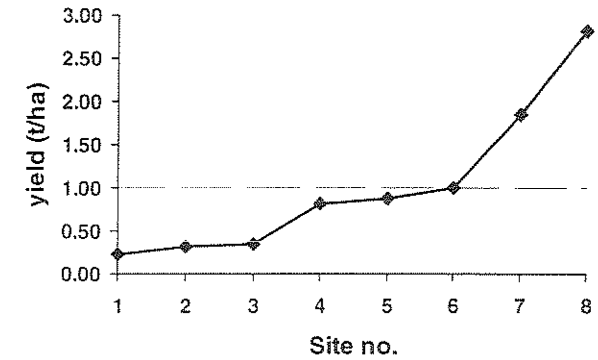


Figure 3: Mean yields for each site under the baseline scenario.

The number of failed sowings doubled successively between sites 8, 7 and 6 with further minor changes once yields had fallen below 1t/ha (Figure 4). The probability of achieving yields >1t/ha fell successively by 25% between sites 8, 7 and 6 (Table 3), with the probability at site 6 falling below 50%

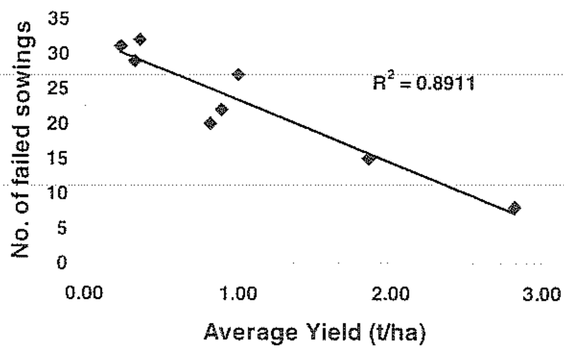


Figure 4: Number of failed sowings compared with average yields under the baseline scenario.

There is a significant drop in the minimum five and ten year running mean yields between site 7 and 6 (Table 3). The ten year average yield for site 6 (Figure 5) shows longer periods of low yields than site 7 (Figure 6).

Table 3: Probability of achieving yields >1 t/ha and minimum 5 year and 10 year mean yields for each site under the baseline scenario. Dotted line represents current cropping boundary

Site	% years >1 t/ha	Minimum 5 year mean	Minimum 10 year mean
1.	3	0.07	0.14
2.	11	0.07	0.16
3.	11	0.07	0.17
4.	38	0.22	0.45
5.	39	0.19	0.26
6.	41	0.09	0.13
7.	66	0.32	0.47
8	90	1.77	2.05

Figure 5: Ten year running mean yields for site 6 (Carrieton) under the baseline scenario.

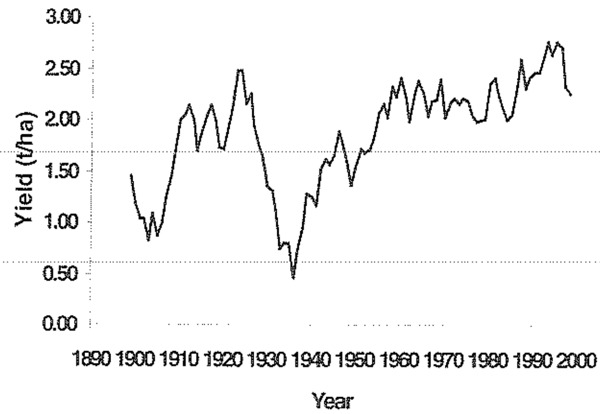


Figure 6: Ten year running mean yields for site 7 (Orroroo) under the baseline scenario.

These analyses all show a distinct discontinuity between sites 6 and 7 which marks the current cropping boundary. The discontinuity results from the strong climatic differences between these two sites (lower and less reliable rainfall and higher evaporation at site 6, data not presented). A mean yield of 1t/ha provides the most simple indicator of this boundary but is also correlated with the other indicators (eg. Figure 4), hence we decided to adopt 1t/ha as the criteria for the cropping boundary for this study.

3.2 Global Change Simulations

CO_2 significantly increased average yields (13-52%) with the response greatest at drier sites (Table 4). Under this elevated 'CO_2' scenario the cropping boundary could move northwards by about 100 km placing it north of site 4 (Table 4).

The increased temperatures under the 'Warm' scenario did moderate the yield increases due to the elevated CO_2 but the boundary remained at site 4 (Table 4). The 'Wet' scenario did not result in significantly different yields from the 'Warm' scenario as the increase in rainfall in this scenario does not occur in the winter growing season.

Under the 'Dry' scenario, average yields declined by 10-35% (Table 4) resulting in the retreat of the boundary from its current position, with site 6 (Carrieton) moving from marginally suitable to unsuitable for cropping (Table 4).

Although the 'most likely' climate change scenario for this region does involve a reduction in rainfall, the cropping boundary is still expected to move northward as far as site 5 (Hawker) (Table 4).

3.3 Historic Increase in CO_2

There was no significant difference between the yields simulated with the historic and 350 ppm CO_2 (data not shown). Most sites did show a small increase in the 10 year running mean yield over recent decades (Figure 5 and 6).

4. DISCUSSION

4.1 Movement of Cropping Boundary

The global change scenarios assessed here, appear likely to affect the distribution of wheat cropping in South Australia. This analysis suggests that there is a high probability of the cropping boundary moving north, even with small reductions in rainfall. However, movement beyond Hawker (site 5) will be limited by the lack of land and soils suitable for cropping in the Flinders Ranges. Historically about 240,000 ha have been cropped beyond Goyder's Line (Foster 1898) and it is likely that an even greater area than this could be cropped under these scenarios. In the south there may also be the opportunity to crop greater areas of soils of lower water holding capacity than is presently practiced.

Under the 'Dry' scenario the movement south of the cropping boundary may have only a minimal impact (order of 10-20,000 ha reduction), as core cropping areas such as Orroroo (site 7) and Jamestown (site 8) remain viable even under this low rainfall scenario.

4.2 Historic Increases in CO_2

The comparison of yields simulated with historic and 350ppm CO_2, shows that the recent expansion of cropping along the current boundary is most likely due to changes in climate or economic factors. Increased CO_2 has only had a very small effect on yields to date.

The current climate data set on which the scenarios are based incorporates existing trends in elements such as minimum temperature. An analysis by Nicholls (1997) has suggested that 30-50% of Australia's yield increases are due to climate trends with changes in minimum temperature being the dominant influence.

Table 4: Mean yields (t/ha) for each site and global change scenario. Sites with yields >1t/ha are shaded.

Site	Baseline	CO_2	Warm	Wet	Dry	Most likely
1	0.23	0.35	0.32	0.34	0.19	0.27
2	0.32	0.48	0.43	0.48	0.27	0.38
3	0.35	0.52	0.47	0.52	0.29	0.39
4	0.81	1.13	1.04	1.07	0.75	0.98
5	0.88	1.19	1.10	1.14	0.81	1.01
6	0.99	1.36	1.31	1.42	0.73	1.05
7	1.85	2.59	2.64	2.73	1.55	2.19
8	2.82	3.20	3.41	3.42	2.91	3.19

4.3 Scenario Limitations

There are a range of caveats that need to be applied to these studies. In particular, the simulations represent a 'step increase' in CO_2 concentrations rather than a more realistic 'transient' increase which would result in progressive changes to factors such as the soil carbon/nitrogen dynamics.

Furthermore, soil carbon and nitrogen parameters are currently re-initialised each year to values representative of existing conditions. Further studies are needed to address these issues. In addition, the structure of the climate scenarios is predicated on climate variability remaining largely constant under climate change. However, there is growing recognition (e.g Timmerman *et al.* 1999) that there may be changes in the El Niño circulation that affects wheat yields in South Australia (Rimmington and Nicholls 1993). If such changes occur they are likely to have a significant impact on climate change scenarios requiring considerable re-analysis of likely impacts and adaptations.

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