Global Change Impacts on Wheat Production Along an Environmental Gradient in New South Wales

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Abstract: Northern New South Wales produces high-protein wheat worth about $180M/year with about 700,000 ha cropped. The expansion of wheat cropping into this region is relatively recent with cropping first appearing in Moree and Walgett in the late 1950s and early 1960s. Walgett marks the boundary of the Western Division as well as a boundary past which cropping is considered a marginal activity. This cropping boundary is defined by institutional arrangements (ie. Western Lands Act) which limit land use in the Western Division to grazing unless a cropping license is obtained. However, changes in commodity prices have seen the relative viability of dryland cropping in these marginal areas increase. As a result there is growing pressure from landholders in the region to allow greater cropping to the west of Brewarrina, requiring policy changes. If policy makers are to make decisions on long term sustainability, the impacts of possible global change need to be taken into account. This paper suggests that there are likely to be shifts in the wheat cropping boundary in northern New South Wales under global change. There may be a movement of the potential cropping boundary to the west under elevated CO_2, even with increased temperatures and small reductions (2.5%) in rainfall. However, suitable soils become limited in extent further west thus restricting the regional significance of these impacts to perhaps several tens of thousand of hectares adjacent to the river systems where suitable soils occur. In contrast, under the Dry scenario the movement east of the cropping boundary may have a large regional impact due to the extensive area of suitable soils, with up to 300,000 ha potentially becoming unsuitable or marginal for cropping. Longer term analyses (ie. beyond 2100) are likely to result in a diminishing response of plants to additional increases in atmospheric CO_2 but continuing and growing impacts of climate change. Study limitations are addressed.

Keywords: Climate change; Wheat; Greenhouse effect; Carbon dioxide; CO_2

1. INTRODUCTION

Northern New South Wales (NSW) produces high-protein wheat worth about $180M/year with about 700,000 ha cropped (Figure 1). The expansion of wheat cropping into this region is relatively recent with cropping first appearing in Moree and Walgett in the late 1950s and early 1960s [Hayman and Alston, 1999]. Previously, cropping had only occurred on small areas of properties to produce grain and fodder for stock [SCS, 1982].

Walgett marks the boundary of the Western Division of NSW as well as a boundary past which cropping is considered a marginal activity. This cropping boundary is defined by institutional arrangements (ie. Western Lands Act) which limit land use in the Western Division to grazing unless a cropping license is obtained. Dryland cropping is now a well established land use in the Walgett area, with smaller less established areas westwards towards Brewarrina. Opportunistic cropping does occur in areas as far west as Bourke through the use of lake bed cropping to manage production risk.

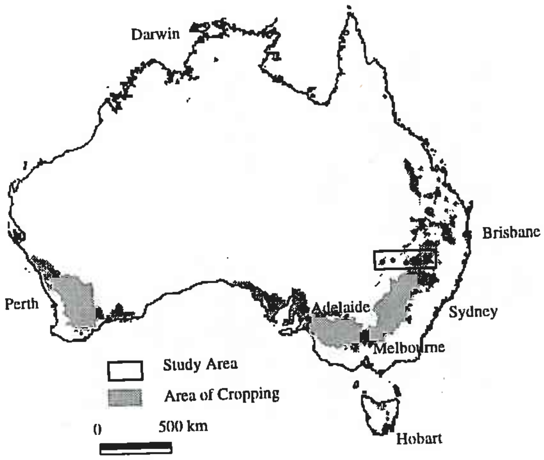

Figure 1. Area of cropping in Australia and location of the NSW transect (rectangle). The rectangle and dots are the transect and sites within.

The continued decline in wool and beef commodity prices and increases in wheat prices has seen the relative viability of dryland cropping in these marginal areas increase. As a result there is growing pressure from landholders in the region to allow greater cropping to the west of Brewarrina. Authorisation under the Western Lands Act to allow land use intensification (i.e. cropping) triggers the Environmental Planning and Assessment Act which requires farms to demonstrate an absence of adverse impacts and/or means to ameliorate adverse impacts. Authorisation will not be given if cropping is not considered economically viable or ecologically sustainable in the long term. Climate change and increased levels of atmospheric carbon dioxide could *a priori* be considered likely to affect viability and sustainability. Hence, if policy makers are to make decisions on long term sustainability, the impacts of possible global change needs to be taken into account.

The aim of this study was to assess whether the current sustainable cropping boundary is likely to move under different scenarios of CO_2 and climate change.

2. METHODS

2.1 Description of Study Area

The study region is a 450 km east-west transect from Moree (29° 28'S 149° 51'E, average rainfall 570mm) to Louth (30° 32' S 145° 07' E, average rainfall 300mm) in New South Wales (Figure 2).

Both rainfall and soil quality decrease from east to west. In the east there are large areas of the naturally fertile cracking clay soils with increasing areas of massive earth to the west. We have restricted the impacts analysis to the cracking clay soils as the massive earth soils in the west of the transect have inherently low fertility and are generally only considered suitable for grazing.

2.2 Simulation Scenarios

The I_WHEAT model [Reyenga *et al.*, 1999; Meinke *et al.* 1998] running in the APSIM modelling environment [McCown *et al.*, 1996] was used to simulate wheat grain yield and nitrogen contents for short fallow systems under a range of CO_2 and climate change scenarios.

Interactions of elevated CO_2 and climate change on wheat production were investigated using five climate scenarios (Table 1); (1) historical climate and CO_2 levels; (2) historic climate with elevated CO_2 (700 ppm), (3) warmer climate (+2.8°C) + 700 ppm CO_2; (4) drier climate (-20% rainfall) + 2.8°C + 700 ppm CO_2; and (5) 'most likely' climate changes (+2.8°C, -2.5% annual rainfall) + 700 ppm CO_2. These global change scenarios were developed using the Monte Carlo sampling approach of Howden and Jones [2001] and the IPCC [2000] emissions scenarios which suggest a mid-range concentration of CO_2 of about 700ppm in the year 2100. These CO_2 concentrations are which translates these concentrations into rates of global warming [IPCC, 2001] and then rates of temperature and precipitation change per degree global warming for Australia [e.g. Jones, 1998]. The 20% rainfall reduction is the ninth decile value, whilst the –2.5% rainfall reduction is the median of the distribution. The change of 2.8°C is the median temperature increase.

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 (1957-1998) for the sites was generated by using interpolated daily

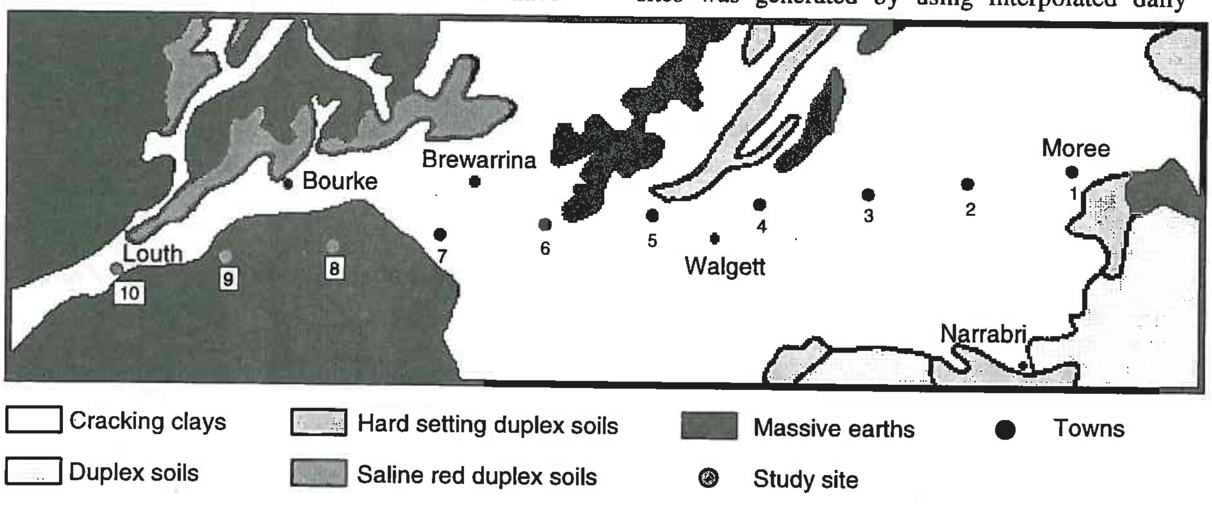

Figure 2. Location of study sites and key soil types (see also Figure 1).

climate surfaces [Carter et al., 1996]. Changes in temperature were added to both maximum and minimum temperatures. Daily rainfall was modified by the proportion defined by the scenarios, with no change to the frequency of rainfall days.

Table 1. Changes in temperature and summer and winter rainfall for each global change scenario. CO_2 levels were 350ppm for the baseline and 700ppm for all other scenarios.

Scenario	Temper -ature (°C)	Summer rainfall (%)	Winter rainfall (%)
Baseline	0	0	0
CO_2	0	0	0
Warm	2.8	0	0
Dry	2.8	-20	-20
'Most likely'	2	-2.5	-2.5

2.1.1 Planting Rules

Simulated sowing can occur within the given planting window (10 May – 11 August) four days after the rainfall requirement has been met. As the reliability of rainfall differs across the transect, sites 1 to 3 only required 20 mm of rainfall (accumulated over two days) for sowing while the remaining sites required 25 mm. Seeds are sown at a density of 80 plants/m^2 at a depth of 50 mm. A summer fallow is simulated with the water balance carried through the entire run. The nitrogen levels were re-initialised each year as simulating nitrogen rundown or buildup was not feasible in a study of this type.

2.3 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 hence gross margins. The viability of a region could be also be determined by the probability of achieving a certain threshold yield (ie. 1t/ha). We analyse these different criteria for their suitability as indicators of current and future cropping boundaries. Gross margins are calculated using the methodology of Howden et al. [1999].

3. RESULTS

3.1 Developing Boundary Criteria

On the basis of existing cropping practice there appears to be a definable boundary for dryland cropping between sites 5 and 6. Rather than a distinct cropping boundary, the baseline simulation show a continuum with a 'transition zone' around sites 4, 5 and 6 where there are large drops in all indicators (Table 2), with the largest drop occurring between sites 5 and 6.

Criteria based on the average of sites 5 and 6 for each indicator were used to assess potential changes in the cropping frontier under the different climate change scenarios. As all indicators gave very similar results only the assessment based on average yield are presented.

Table 2. Mean yields, gross margins and the probability of achieving yields greater than 1 t/ha and 1.5 t/ha for each site under the baseline scenario. Dotted line represents current cropping boundary.

Site	Yield (t/ha)	Gross Margins ($/ha)	% years >1 t/ha	% years >1.5 t/ha
1	2.30	237	81	79
2	2.14	217	79	71
3	1.96	193	76	69
4	1.85	172	71	67
5	1.62	130	64	60
6	1.32	89	55	50
7	1.29	62	55	48
8	1.11	50	50	45
9	1.10	45	50	43
10	0.86	18	40	38

Table 3. Mean yields (t/ha) for each site and global change scenario. Sites with yields ≥1.5t/ha are shaded.

Site	Baseline	CO_2	Warm	Dry	Most likely
1	2.30	2.77	2.61	2.18	2.60
2	2.14	2.60	2.46	1.99	2.47
3	1.96	2.42	2.30	1.58	2.29
4	1.85	2.30	2.14	1.38	2.02
5	1.62	2.01	1.92	1.32	1.83
6	1.32	1.66	1.56	1.14	1.55
7	1.29	1.65	1.49	0.95	1.40
8	1.11	1.41	1.31	0.80	1.23
9	1.10	1.40	1.29	0.71	1.25
10	0.86	1.09	0.99	0.41	0.82

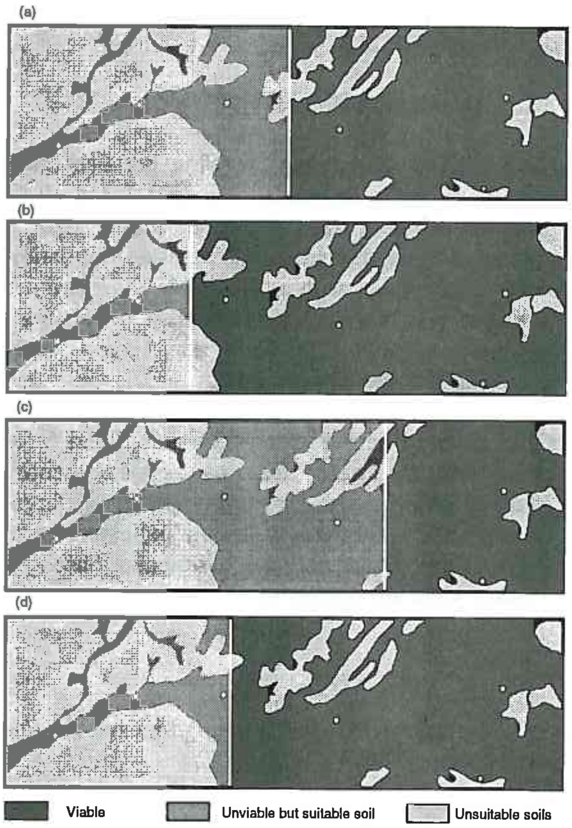

Figure 3. Area potentially viable for cropping under the (a) Baseline, (b) CO_2 (c) Dry and (d) 'Most likely' scenarios

3.2 Global Change Simulations

CO_2 significantly increased average yields (20-28%) with the response greatest at drier sites (Table 3). Under the elevated 'CO_2' scenario the cropping boundary could move westwards by about 150 km placing it west of site 7 (Figure 3).

The increased temperatures under the 'Warm' scenario did moderate the yield increases due to the elevated CO_2 with the boundary occurring at site 7 (Table 3).

Under the 'Dry' scenario, average yields declined by 5-53% (Table 3) resulting in a significant retreat of the boundary from its current position, with areas beyond site 3 becoming unsuitable for cropping (Figure 3).

Although the 'most likely' climate change scenario for this region does involve a reduction (2.5%) in rainfall, the cropping boundary is still expected to move westward between sites 6 and 7 (Table 3, Figure 3).

4. DISCUSSION

This study suggests that there are likely to be shifts in the wheat cropping boundary in northern New South Wales under global change. The likely changes in the frontier determined by the different boundary criteria were consistent.

These analyses show a movement of the cropping boundary to the west under elevated CO_2, even with increased temperatures and small reductions (2.5%) in rainfall. This is due to the substantial beneficial impact of increased levels of atmospheric carbon dioxide in dry environments [Howden et al. 1999]. However, suitable soils become limited in extent further west thus restricting the regional significance of these impacts to perhaps several tens of thousand of hectares adjacent to the river systems where the soils are more fertile both physically and chemically. In the east of the transect there may also be the opportunity to crop substantial areas of soils of lower water holding capacity than is presently practiced. However, such activity may be restricted through possible Kyoto Protocol commitments because cropping previously undisturbed soil can result in loss of up to 50% of the soil carbon – presumably most of it emitted as CO_2 into the atmosphere [e.g. Dalal and Mayer, 1986; Post and Mann, 1990].

In contrast, under the Dry scenario the movement east of the cropping boundary may have a large regional impact due to the extensive area of suitable soils, with up to 300,000 ha potentially becoming unsuitable or marginal for cropping. Presumably other landuses such as grazing or farm forestry may replace cropping. In both cases, carbon sequestration may occur and (if this storage becomes tradeable), may possibly offset some of the income lost from the cessation of cropping.

While there is a probability of the cropping boundary moving west under global change, increasing the area of cropping and improving yields in areas currently cropped, there remains a considerable chance that the boundary may move east as the full range of possible climates exceeds those used here. For example, increases in temperature of up to 5°C are possible by 2100 and decreases in rainfall of –30%. Furthermore, longer term analyses (ie. beyond 2100) are likely to result in a diminishing response of plants to additional increases in atmospheric CO_2 but continuing and growing impacts of climate change. Hence there remains a considerable risk from climate change on the cropping industry in the region as the beneficial consequences are marginal (even though apparently more likely) whilst the negative consequences could be quite severe (even though less likely).

4.1 Study limitations

There is a range of caveats, relating to the representations of CO_2 and climate change and the sustainability of cropping, that need to be considered in association with the findings of this study.

These 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. 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 Meehl and Washington, 1996; Wilson and Hunt, 1997; Timmerman et al., 1999] that there may be changes in the El Niño circulation that affects wheat yields in eastern 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.

These simulations only represent a potential yield analysis as we have not addressed sustainability of cropping. The sustainability of cropping in the long term will be highly dependent on specific management practices implemented (e.g. zero-tillage, direct drill) whereas currently the simulations are based on generalised soil types and management practices. Other factors affecting sustainability which we did not fully address include:

- Risk of salinisation and acidification
- Nutrient rundown and buildup.
- Changes in the economic sustainability of cropping due to changes in the price of wheat.
- Possible management and crop adaptations to global change.

There remains a need to assess these before a more definitive impact of climate change on cropping in the region can be made.

5. ACKNOWLEDGEMENTS

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