Managing the quality of wheat grain under global change

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Abstract: Atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases are increasing as a result of human activities. These increasing concentrations are already affecting the global climate and more substantial climate change seems likely. Grain yields in Australia are likely to increase substantially with increases in CO_2 concentration but at the cost of reducing grain nitrogen (or protein) contents, thereby reducing the price premium for high nitrogen grain. Adaptations such as increased nitrogenous fertiliser application will thus be needed to counter these reductions in quality. However, the required fertiliser management will vary with climate change scenarios, and these remain highly uncertain. We assessed the likely impacts of CO_2 increase (doubling current concentration to about 700ppm) and climate change scenarios ($\pm$ 20% change in rainfall and 2°C or 4°C temperature increase) on wheat cropping systems in two contrasting environments in Australia: Dalby in the summer-dominated rainfall subtropics of Queensland and Wongan Hills in the Mediterranean climate of south-western Western Australia. If in conjunction with increased CO_2 concentration there is either no change or increased rainfall, then gross margins are likely to increase so that farmers can *partly* adapt to reductions in the grain protein content through moderate application of fertiliser; higher application rates are unlikely to increase them further but increase externalities such as greenhouse emissions. However, if climate change results in a significant reduction in rainfall, gross margins could be significantly reduced, notwithstanding the 'CO_2 fertilisation effect'. Higher temperatures reduced the demand for additional fertiliser but also reduced yield and gross margin. Recent climate change scenarios indicate significant reductions in rainfall across the southern grain-growing regions of Australia. If these scenarios are a reasonable representation of future climate change, then gross margins are likely to fall at Wongan Hills regardless of the fertiliser management used. In contrast, at Dalby, gross margins may be maintained with moderate fertiliser rates but this will result in a mean reduction in nitrogen content and greater number of years when the grain does not meet 'hard' wheat quality. Additional adaptations are 1) further development of crop management to maintain soil nitrogen status 2) instigation of breeding programs to maintain grain protein contents under elevated CO_2 concentrations and 3) management aimed at conserving water.

Keywords: *climate change, wheat, nitrogen, fertilizer, grain quality, Australia*

1. INTRODUCTION

Whilst grain yields are considered likely to increase over the next 100 years due to increasing concentrations of carbon dioxide (CO_2) in the atmosphere (Cure and Acock 1986, Howden *et al.* 1999), this is likely to occur at the cost of reducing grain protein (or nitrogen) contents (e.g. Rogers *et al.* 1996, Wolf 1996, Howden *et al.* 1999, Kimball *et al.* 2001). Howden *et al.* (1999) simulated mean reductions in grain nitrogen of 9-15% with doubled CO_2 and 4-14% with CO_2 change and climate change across Australia. In the absence of any adaptive management responses (e.g. additional N fertiliser applications), these changes are likely to be quite significant in downgrading grain quality, representing a reduction in one to two quality classes – foregoing a premium of up to \$70 a tonne on average (about 30%). Adaptations may thus be needed to counter these changes in grain quality either through changes in management practices such as the addition of fertiliser (Reyenga *et al.* 1999) or breeding new cultivars more suited to higher concentrations of CO_2.

The aim of this report was to assess the changes in fertiliser application rates that would be required to maintain grain nitrogen contents at simulated historical levels. This assessment was undertaken at two sites with contrasting climate and soil conditions.

2. METHODS

The Queensland wheat region produces high protein wheat for specific end-use markets, for example, prime hard noodle wheat, durum wheat and domestic bread wheat. For this region, wheat produced with a grain protein content below 11.5% (~2%N) is considered acutely nitrogen deficient. Profits suffer due to lost yield and low protein levels causing downgrading to a lower premium classification (QDPI 1999). In Western Australia, the majority of wheat produced is the Australian Standard White which has protein levels of about 10.5% (~1.8%N).

The modified wheat model I_WHEAT (Meinke *et al.* 1998, Reyenga *et al.* 1999) part of the APSIM framework (Keating et al., 2003) was used to simulate wheat yields and grain nitrogen levels for two study sites 1) Dalby in Queensland (average rainfall 676mm) and 2) Wongan Hills in Western Australia (average rainfall 390mm). A modelling approach allows the assessment of climate factors alone without the confounding effects of technology and economic trends. The two sites were chosen as they are contrasting in several respects. Dalby is in a summer-dominated rainfall zone in the sub-tropics, has heavy self-mulching fertile soils and traditionally grows high-protein 'hard' wheats. Wongan Hills in contrast has light, sandy, infertile soils, a strongly Mediterranean (winter dominated rainfall) climate in the temperate zone and traditionally produces softer 'standard' lower protein grains.

We assessed the amount of fertiliser required to maintain the current probability of exceeding the key nitrogen thresholds (2% for Dalby and 1.8% for Wongan Hills) under the different global change scenarios. The gross margins (calculated as per Howden *et al.* (1999)) for each scenario were also assessed.

Interactions of elevated CO_2, climate change and fertiliser on grain nitrogen were investigated using a factorial combination of climate change scenarios and fertiliser rates; 700ppm CO_2 *x* temperature change (0, 2 and 4°C increase) *x* rainfall change (–20, 0, and 20% changes) *x* fertiliser application rate (80, 125, 175, 225, 275, 325, 375 kg N/ha), compared with a baseline scenario (350 ppm CO_2,and historical climate with the same range of fertiliser applications).

The use of 80kg fertiliser in the lowest fertiliser rate for the baseline simulations may be somewhat higher than recent regional norms (McLeish and Flavel 1996) but is adequate to ensure that nitrogen inputs at least balance outgoings; a strategy now adopted by many farmers (Hayman and Alston 1999).

The historic climate records were modified by adding the temperature changes to both the minimum and maximum temperatures, and by increasing rainfall by the proportion defined by the scenario (e.g. Howden *et al.* 1999). No changes were made to the frequency of rainfall days.

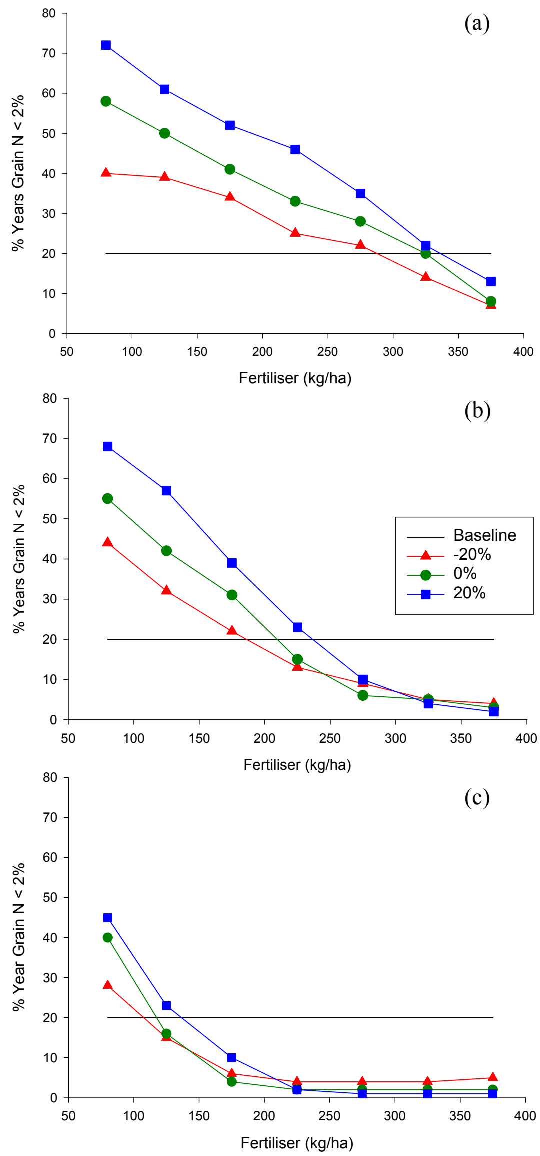

Figure 1: Percent of years at Dalby when grain nitrogen is less than the 2% threshold for the (a) 0°C (b) 2°C and (c) 4°C temperature scenarios under the different fertiliser application and rainfall scenarios. The Baseline simulation was only for the lowest rate of 80kgN/year.

For these simulations, the model was run assuming a continuous wheat monoculture, with the soil water balance maintained between crops. Soil N and organic matter were reset at sowing. The 'standard' crop varietal strategy, planting rules and soil types used are those defined by Howden *et al.* (1999) for each of the sites.

3. RESULTS

3.1 Dalby – Queensland

3.1.1 Grain Nitrogen

Average nitrogen content of the grain under the baseline scenario was 2.29% with levels falling below the threshold of 2% in only 20% of years (Figure 1). With the doubling of CO_2 and no change in fertiliser application rates, grain nitrogen levels were reduced by about 10% with the threshold not being met in 58% of years (Figure 1a). Nitrogen levels declined by 15% under the +20% rainfall and 0°C scenario with the threshold not being met in 72% of years (Figure 1a). While on average the quality of the grain was maintained under the –20% rainfall and +4°C scenario, the probability of not meeting the threshold increased from baseline levels by 40% (Figure 1c).

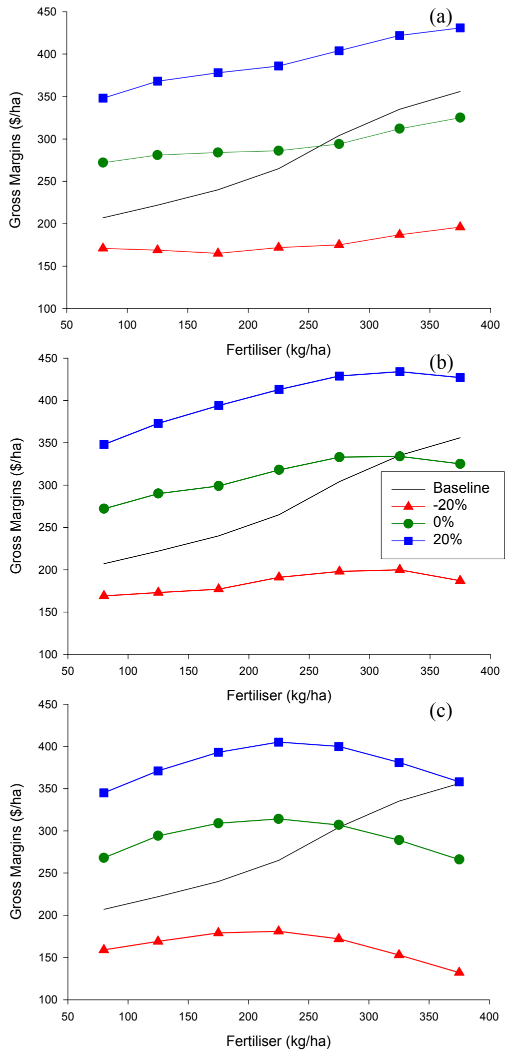

Figure 2: Gross Margins ($/ha) for wheat in Dalby for the (a) 0°C (b) 2°C and (c) 4°C temperature scenarios under the different fertiliser application and rainfall scenarios

Under the scenario with no change in temperature, between 275 and 325 kg/N was required to achieve a similar probability of exceeding the grain nitrogen threshold as the baseline (Figure 1a). As temperatures increased, less fertiliser was required due to increased soil nitrogen mineralisation rates. For example, between 175 and 225 kg/N were needed in the 2°C scenario compared with only about 125 kg/N in the 4°C scenario (Figure 1a,b). The amount needed differed between rainfall scenarios with more fertiliser being required in the higher rainfall scenarios.

3.1.2 Gross Margins

Based on 1994 to 1999 costs and prices, average gross margins (GM) under the baseline were estimated to be $207/ha. Doubling of CO_2 alone resulted in a 31% increase in gross margins (Figure 2a). Gross margins increased with increased rainfall, with the maximum change in GM (68%) achieved with the +20% rainfall and 2°C scenario and the lowest (-23%) occurring with the –20% rainfall scenario and 4°C scenario (Figure 2).

Under the baseline climate scenario, increasing fertiliser application rates resulted in higher gross margins. This however, was not the case under all climate change scenarios. Gross margins continued to increase with additional fertiliser under the 0°C temperature change but began declining at fertiliser levels greater than 275 and 225 kg/ha under the 2°C and 4°C scenarios respectively (Figure 2).

3.2 Wongan Hills – Western Australia

3.2.1 Grain Nitrogen

Average nitrogen content of the grain under the baseline scenario was 2.05% with levels falling below the 1.8% threshold in only 17% of years (Figure 3). With the doubling of CO_2, grain nitrogen levels were reduced by about 14% with the threshold not being met in 53% of years (Figure 3a). Nitrogen levels declined by 17% on average under the +20% rainfall and 0°C scenario with the threshold not being met in 64% of years (Figure 1a). While on average the nitrogen content of the grain was increased (+9%) under the –20% rainfall and +4°C scenario, the probability of not meeting the threshold increased to 33% (Figure 3c).

Under the scenarios with no change in temperature, between 225 and 325 kg/N were required to achieve a similar probability of exceeding the grain nitrogen threshold as the baseline (Figure 3a). As temperatures increased, less fertiliser was required. For example, between 125 and 225 kg/N were needed in the 2°C scenario compared with only 80-125 in the 4°C scenario (Figure 3b,c). The amount needed differed between rainfall scenarios with more fertiliser being required in the higher rainfall scenarios.

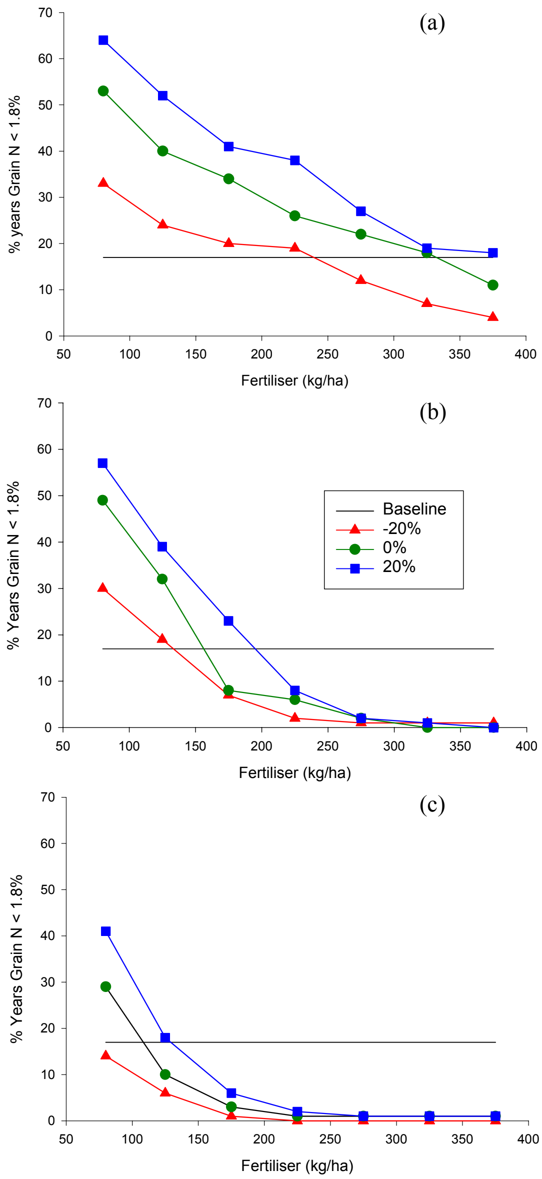

Figure 3: Percent of years in Wongan Hills when grain nitrogen is less than the 1.8% threshold for the (a) 0°C (b) 2°C and (c) 4°C temperature scenarios under the different fertiliser application and rainfall scenarios. The Baseline simulation was only for the lowest rate of 80kgN/year.

3.2.2 Gross Margins

Average gross margins (GM) under the baseline scenario were estimated to be \$165/ha. Doubling of CO_2 alone resulted in a 32% increase in gross margins (Figure 4). The maximum change in GM (58%) was simulated with the +20% rainfall and 2°C scenario and the lowest (-27%) occurred with the –20% rainfall and 0°C scenario (Figure 4).

Under the baseline climate scenario, increasing fertiliser application rates resulted in lower gross margins. For scenarios with rainfall reductions, after an initial increase in gross margins as the level of fertiliser was increased to 125 kg/ha, gross margins generally declined. The response in the +20% and 0% rainfall scenarios differed depending on the temperature change. After an initial increase in gross margins at 125 kg N/ha, gross margins declined under the 0°C temperature scenario, increased in the 2°C scenario and increased up to 225kg N/ha in the 4°C scenario (Figure 4) but declined with higher application rates.

4. DISCUSSION

Increased CO_2 and climate change reduced both the average grain nitrogen levels and the frequency of achieving key nitrogen thresholds. To maintain grain nitrogen contents at simulated historical levels, there will be a need to increase fertiliser application rates above the baseline rate of 80kgN/ha/year by 40 to 240 kg N/ha depending on the future scenario. For the Wongan Hills site, this is unlikely to be realistic as the high fertiliser rates needed are supra-optimal in terms of gross margins for all climate change scenarios. Nevertheless, small increases in nitrogen applications (i.e. 40kg/ha/year) are likely to improve gross margins. Improved nitrogen nutrition using rotations with nitrogen-fixing species could also be used to achieve this goal although they were not investigated here in these continuous cropping simulations. As a general rule, less fertiliser was required to offset nitrogen declines under the higher temperature scenarios due to increased soil nitrogen mineralisation while more fertiliser was required under the higher rainfall scenarios due to greater leaching as found by van Ittersum et al. (2003). The increased nitrogen available from mineralisation under warmer climates will be a transient effect whilst soil carbon is equilibrating to lower levels. The step-change in climate used here and the re-setting of soil carbon and nitrogen pools each year are likely to result in over-estimates of this temperature effect. Similarly, the annual resetting of nitrogen prevented its accumulation that would result with increasing application rates. Accumulation of nitrogen is associated with negative impacts such as leaching, eutrophication of waterways and acidification of soils. Thus, the higher rates of simulated N application are unrealistic but useful to benchmark systems responses to N application rates. This simulation design allowed orthogonal comparisons between treatments: which would otherwise have had confounding effects (e.g. van Ittersum *et al.* 2003).

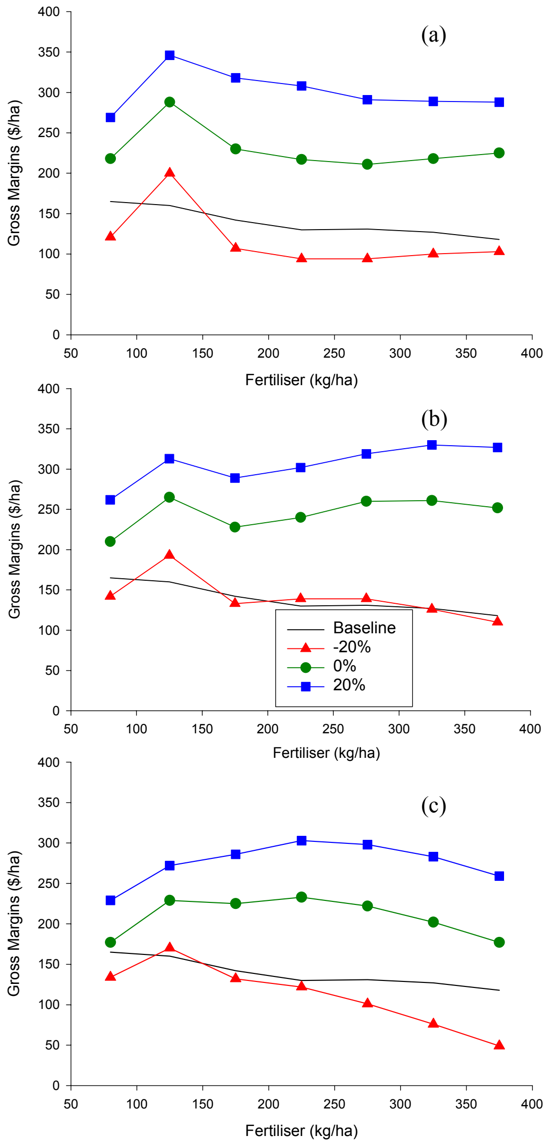

Figure 4: Gross Margins ($/ha) for wheat in Wongan Hills for the (a) 0°C (b) 2°C and (c) 4°C temperature scenarios under the different fertiliser application and rainfall scenarios.

While the price received for each unit of grain is reduced with elevated CO_2 due to lower protein contents (in line with existing relationships), the higher yields achieved result in an increase in gross margins. Under the baseline climate scenario, the ability of crops to respond to increased fertiliser differed between sites with gross margins continuing to increase at the higher fertiliser application rates in Dalby but declining at Wongan Hills. Under the scenarios with either no change in rainfall or with 20% increase in rainfall, applying fertiliser at the rates required to offset the decline in grain N produced gross margins that exceeded those under the baseline simulations. However, gross margins under the dry climate change scenarios (-20% rainfall) were consistently lower than those achieved under the baseline simulations.

This analysis suggests a general result that if climate changes results in no change or increases in rainfall, then farmers could partly adapt to reductions in the grain protein content through application of fertiliser without a reduction in their gross margins. However, if climate change results in a significant reduction in rainfall, gross margins could also be significantly reduced, notwithstanding the ‘CO_2 fertilisation effect’. Recent climate change scenarios suggest that such reductions in rainfall appear to be likely across the southern grain-growing regions of Australia.

Recent climate change scenarios for the year 2070 using results from an array of global climate models suggest changes in autumn, winter and spring rainfall from 10% increase to a 60% decrease for the Wongan Hills region (CSIRO 2001) For Dalby, these scenarios provide less strong indications of drying, with uncertain summer and autumn rainfall changes ($\pm$35%) but some indications of lower rainfall in winter and spring (+10% to –35%). Presumably the results for the year 2100 suggest even greater rainfall reductions. Mean temperature changes for the two locations are 2.4 to 2.6°C respectively but again are highly uncertain (1 to 6°C).

If these scenarios are a reasonable representation of future climate change, then gross margins are likely to fall at Wongan Hills regardless of the fertiliser management used. In contrast, at Dalby, gross margins may be maintained with the low fertiliser regimes but this will result in a mean reduction in nitrogen content and greater number of years when the grain does not meet ‘hard’ wheat quality. Key adaptations appear to be 1) instigation of breeding programs to maintain grain protein contents under elevated CO_2 concentrations 2) further development of crop management to maintain soil nitrogen status and 3) management to conserve water (Howden et al. 2003).

It is important to note that the gross margin analysis is based on 1994 to 1999 wheat prices and fertiliser costs. These could be expected to vary significantly by the year 2100 due to the highly uncertain changes in global supply and demand for both wheat and fertilisers. Existing assessments of long-term grain prices based on supply-demand ratios with a range of global change scenarios suggest a range from little change in prices to some increases (Rosenzweig and Parry 1994). Fertiliser prices seem likely to increase as a result of higher prices for natural gas – indicative forecasts suggest increases by up to 25% over the next 25 years (EIA 2003).

The adaptations of fertiliser application and change in rotations will have their own impacts on soil acidification processes and water quality in some regions, the ratio of sown pasture to crop in mixed farming systems and on farm economics. Furthermore, such adaptation could be a significant source of greenhouse gas emissions as 1)production, packaging and distribution of nitrogenous fertiliser generates about 5.5 kg CO_2 per kg N (Leach 1976) and 2) as both fertilisation and legume rotations increase emissions of the potent greenhouse gas nitrous oxide (Prather et al. 1995).

5. ACKNOWLEDGEMENTS

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