

# Crop N & P demand under climate change

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## SUMMARY

Rising atmospheric carbon dioxide concentration will result in drier and warmer conditions across much of the mid-latitudes, including Australia and New Zealand. Research at the Australian Grains Free Air Carbon Dioxide facility has shown that although yield increased due to improved C supply, wheat grain protein, baking quality and important micronutrients all decline.

Future farming systems will require cultivars adapted to higher carbon dioxide levels and new combinations of nutrient source, rate, time and place to meet the change in the pattern of nutrient demand.

## INTRODUCTION

Atmospheric carbon dioxide (CO<sub>2</sub>) has been rising since the industrial revolution, and at the present rate will reach about 550  $\mu\text{mol mol}^{-1}$  by 2050. This increase, along with the consequent perturbations of climate will profoundly influence food production and farming systems. Higher CO<sub>2</sub> levels are generally reported to stimulate growth in C3 plants. Uncertainty about how this increase would interact with hotter and drier growing conditions led to the establishment of the Australian Grains Free Air Carbon Dioxide Enrichment (AGFACE) facility in 2007. We provide an overview of the results from the AGFACE research group relating to wheat crop nutrition.

## METHODS

The AGFACE facility is at Horsham (36.7519°S, 142.1144°E) in southeastern Australia. The facility has 8 elevated CO<sub>2</sub> FACE rings (~550  $\mu\text{mol mol}^{-1}$ ) and 8 control (~385  $\mu\text{mol mol}^{-1}$ ) rings with 12 m rings and 12 plots each 4 m by 1.7 m per ring (2007/2008) or 16 m rings with 24 plots (after 2009). These main CO<sub>2</sub> effects are combined with different water supply (by irrigation), temperature during grain fill (by altering sowing time), nitrogen (by fertilizer) and cultivar. CO<sub>2</sub> was injected over the crop in open-air rings from emergence until maturity in 2007, 2008 and 2009 (Mollah et al. 2009). Growth, yield, water use, grain mineral content and yield have been measured for each of the treatments and these data analysed as a factorial analysis of variance.

## RESULTS AND DISCUSSION

### *Growth and Yield*

Elevated CO<sub>2</sub> increased crop biomass at maturity by 22% (2007), 31% (2008) and 32% (2009). Mean grain yield of two common wheat cultivars (Yitpi and Janz) increased on average from 252 g m<sup>-2</sup> to 322 g m<sup>-2</sup> when grown under elevated CO<sub>2</sub> (Table 1). Sowing time and additional water affected growth and yield with the later sowing showing no response to higher CO<sub>2</sub> in one of the three years (2008.) In two of three years, kernel weight increased with higher CO<sub>2</sub> although there was no consistent change in other yield components (Norton et al. 2010).

The increase in growth generally occurred during the spring rather than the cooler winter months. An important outcome of the research is that the stimulation occurs in most situations, even under warmer and drier climates. Harvest index – the ratio of grain to growth was not affected under eCO<sub>2</sub> but the drier and hotter conditions are likely to adversely affect this ratio leading to crops “hayng off” (Nutall et al. 2012).

### ***Increased nutrient demand***

When grown under elevated CO<sub>2</sub>, plants had lower tissue N content particularly later in growth, but there were few interactions with temperature, water or cultivar. For example, in 2008 leaf N concentration at flowering declined from 3.8% to 3.5% ( $p < 0.00$ ) (Norton et al. 2010) although the lower leaf N content did not compromise photosynthetic capacity as the main photosynthetic enzyme (RubisCo) activity increased (Thilikarthne et al. 2013).

Grain protein at maturity declined significantly in nearly all situations under elevated CO<sub>2</sub> (Table 1). Fernando et al. (2012) showed in one cultivar that protein declined from 15.5% to 13.5%. It is important to understand the mechanism behind this change, so that new cultivars and management systems can be designed to minimise this decrease. For example, Fernando (2013) showed that wheat supplied with ammonium-N showed a smaller protein decline as those supplied with nitrate-N.

Despite this, the demand for N increased due to the stimulation of growth, which may be a consequence of reduced plant N causing less remobilisation from the leaves to the grain during grain filling. When averaged across all the experimental treatments, elevated CO<sub>2</sub> increased crop N removal by 20% (Lam et al. 2012). This indicates that added N will be required by crops growing in future carbon dioxide rich climates.

Table 1. The effect of elevated CO<sub>2</sub> on the grain yield and grain N content of wheat from the AGFACE experiment. All means within a year are significantly different ( $p < 0.05$ ).

Factor	[CO <sub>2</sub> ]	2007	2008	2009
	( $\mu\text{mol/mol}$ )			
Grain yield ( $\text{g m}^{-2}$ )	380	258	247	252
	550	323	310	332
Grain N content (%)	380	2.44	3.16	3.06
	550	2.33	3.04	2.81

Elevated CO<sub>2</sub> did not affect the efficiency at accessing fertilizer N, and in the AGFACE there was no evidence of differences in N mineralisation from crop residues (Lam et al. 2012a). Nitrogen fixation efficiency was not affected by eCO<sub>2</sub>, but legume growth stimulation meant that more N was derived from biological N fixation under elevated CO<sub>2</sub>. This response was dependant on an adequate P supply to the legume (Lam et al. 2012b). The relative value of legume derived N to subsequent cereals may be reduced under elevated CO<sub>2</sub>. However, compared to N fertilizer application, legume incorporation will be more beneficial to grain yield and N supply to subsequent cereals under future climates (Lam et al. 2013). There is no evidence that crops grown under eCO<sub>2</sub> have a higher efficiency of P uptake or access to different soil P pools (Jin et al. 2013a). This was despite more microbial activity around the roots of plants under eCO<sub>2</sub>, probably due to increased production of root exudates (Jin et al. 2013b).

Concentration of grain S, Ca, Zn and Fe decreased in wheat grown under elevated CO<sub>2</sub>. This could not be fully explained by “yield dilution and the N:S ratio also declined (Fernando et al. 2012). As well as changing the amount of grain protein, the types of proteins also changes, which affects baking quality. The reduction in grain protein was correlated with Fe, Zn, and S concentration, so that elevated CO<sub>2</sub> is likely to exaggerate worldwide Fe and Zn malnutrition for those on grain-based diets, although lower grain phytate concentrations may offset some of this decline (Fernando et al. 2012).

### ***Climate impacts on future nutrient demand***

It is difficult to upscale these results to national or international levels, as there are other challenges facing agricultural production most importantly the need to increase food quantity and quality to the extra 2 billion people by 2050, which at the same time ensuring a clean and healthy environment. These issues are not mutually exclusive, and good agricultural practice has positive outcomes for both production and the environment.

With current C3 crops, 2050 atmospheric [CO<sub>2</sub>] could increase N demand by 20%, and that higher N demand will require balanced nutrition with extra P, K, S and micronutrients.

## **CONCLUSIONS**

This research identified that nutrient management strategies will need review under elevated CO<sub>2</sub>. The pattern of growth, and therefore the temporal pattern of nutrient demand mean new combinations of the nutrient source, rate, time, and place will be needed, along with more efficient cultivars.

Most important will be development of strategies to stop protein changes and so maximize the benefits of the extra carbon available. This may be by changing to ammonium based N sources, use of foliar N around grain filling and by building on the current research that is developing more N efficient cultivars.

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