Water use and water use efficiency of wheat under a Free Air CO_2 Enrichment (FACE) experiment

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Abstract
Methods to increase water use efficiency (WUE) of crops have been advocated over the years, ranging from breeding high WUE in crops to agronomic methods that save water supplies to increase the proportion of water available for transpiration. Practical methods for dryland farmers include the use of fallowing and its variants, surface mulches and weed control, which boost crop water use through greater transpiration. We examined the response of wheat crops grown over three years at the Australian Grains Free Air CO_2 Enrichment (FACE) facility to growth, yield and water use. The experiment included multiple cultivars but we restricted our measurements to one cultivar (cv. Yipti) that was grown under two water regimes (rain-fed and supplemental irrigation) and two nitrogen fertilisation regimes (0 and 53-138 kg N/ha) for both ambient (365 ppm) and elevated (550 ppm) CO_2 atmospheric conditions. Grain yield responses to elevated CO_2 were large (mean +25%) and consistent for both above-ground biomass and grain yield. WUE was increased under elevated CO_2 (mean +30%) with evidence ($P<0.10$) of reduced water use (mean 7%) contributing to the increased efficiency.

Key words
Climate change, simulation models, transpiration efficiency

Introduction
Crop growth and yield is expected to increase under elevated CO_2 (eCO_2) as atmospheric CO_2 levels continue to rise (Ainsworth and Long 2005; Ainsworth et al. 2008; Leakey et al. 2009). The extent of the expected yield gains will also depend on other limiting factors that might increase or decrease the response. Such factors are shortages of water supply where the relative response to eCO_2 has been reported sometimes to be greater under drought than luxurious water supply (Amthor 2001). Modelling studies have reported greater yield increases under drought (Ludwig and Asseng 2006), but not always and the more extreme effects of high temperature might otherwise negate potential gains from eCO_2 (Amthor 2001; Anwar et al. 2007; O'Leary et al. 2011).

This study examines the water use and water use efficiency of one wheat cultivar (cv. Yitpi) over three years in the Australian Grains Free Air CO_2 Enrichment (AGFACE) facility at Horsham, Victoria. Increases in biomass and grain yield have previously been reported (Fitzgerald et al. 2010) and this study looks for evidence that this increase can be attributed to increases in water use efficiency via reduced water use. The primary question is, does the gain in crop growth occur because of savings in water in dry environments? If so, can such generalisations be extrapolated beyond the locality of the Horsham AGFACE experiment?

Methods
The AGFACE experiment in Horsham, Australia (Mollah et al. 2009) was used to measure the growth, yield and water use of wheat under various controlled conditions. The experiment included multiple cultivars but we restricted our measurements to one cultivar (cv. Yipti) that was grown under two water regimes (rain-fed and supplemental irrigation) and two nitrogen fertilisation regimes (0 and 53-138 kg N/ha) for both daytime ambient (365 ppm) and elevated (550 ppm) CO_2 atmospheric conditions. We define crop water use as the change in soil water content (mm) during the growing season (sowing to harvest) plus rainfall and irrigation between the sowing and harvest sampling times. This therefore includes losses from soil evaporation, crop transpiration, deep drainage and runoff, with the latter two considered insignificant from a seasonal perspective (i.e. within the error of measurement, after O'Leary and Connor 1997). For example, seasonal drainage is known to be around 20 mm with typical errors of water use for these soils around 50 mm. We define water use efficiency as the grain yield divided by the water use.

Large soil mineral nitrogen content at the site precluded any significant effects of the applied N and so all analyses were pooled across the N treatment.

Data were analysed by simple regression of treatment means (arithmetic) of the eCO_2 treatments against the ambient treatments, forced through zero. This provided a simple way to reduce experimental noise and obtain gross estimates of the effects of eCO_2 on yield, water use and water use efficiency rather than classical ANOVA analyses.

Results and Discussion

Yield response to eCO_2

An overall mean response to eCO_2 of 25% ($P<0.05$) was measured across all agronomic treatments with no consistent differences observed between time of sowing, irrigation treatment or season (year) (Figure 1). For any individual treatment (point) the eCO_2 response is the slope of the line from the origin (0,0) to that point such that the closer to the origin (e.g. very low yield crops) it is likely that the experimental noise will inflate both positive and negative responses. At Horsham in 2007, 2008 and 2009 the effect of eCO_2 was to increase mean yield by 25%.

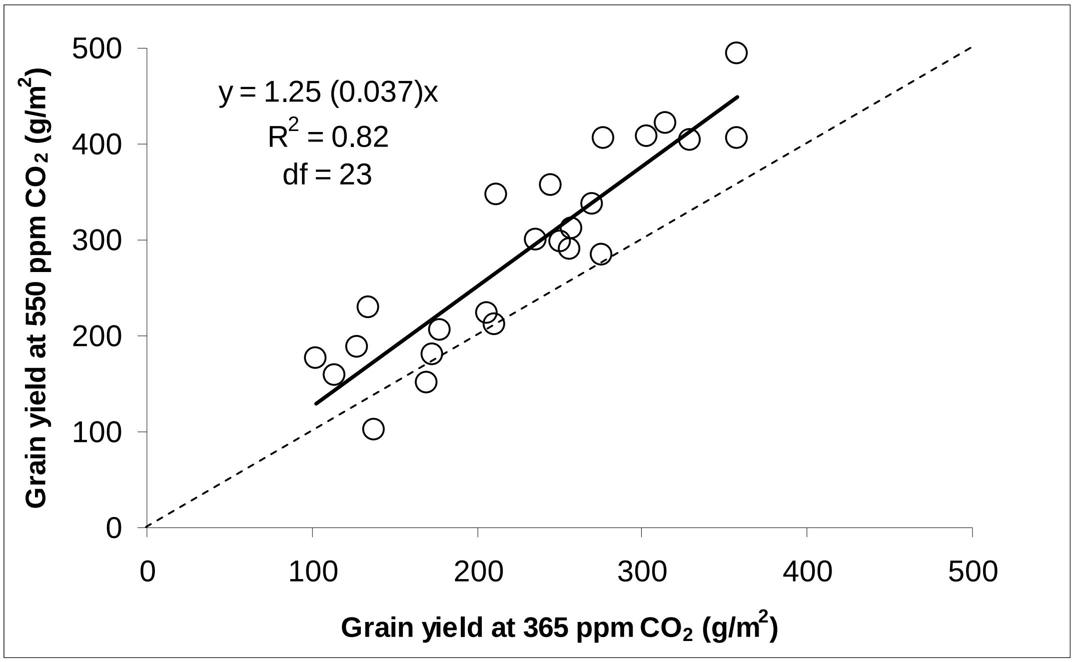

Figure 1. Comparison of grain yield (cv. Yitpi) response under elevated CO_2 compared to daytime ambient conditions (365 ppm) showing significant ($P<0.05$) mean increase in yield (25%) against the 1:1 unity dashed line. Standard error of linear coefficient shown in parentheses.

Water use response to eCO_2

Water use was reduced by eCO_2 by about 7% ($P<0.10$) (Figure 2). Reduced water use, however, was not universally observed with no reduction in one year (data not shown). Whilst the response is close to unity with more variance than in grain yield (lower R^2) the lower overall water use confirms earlier theoretical estimates that savings in water use might occur in the field. One issue with this data set is the large variance coupled with low degrees of freedom (residual df = 11 compared to 23 for yield and WUE). Additionally, our sampling technique comprised of single 50 mm diameter volumetric cores per plot for sowing and harvest sampling. Previous experience in this region has achieved significant least significant differences ($P<0.05$) for water use of around 50 mm from at least four cores per plot (O'Leary and Connor 1997) so a significant result here at the higher level of $P<0.10$ is not unexpected.

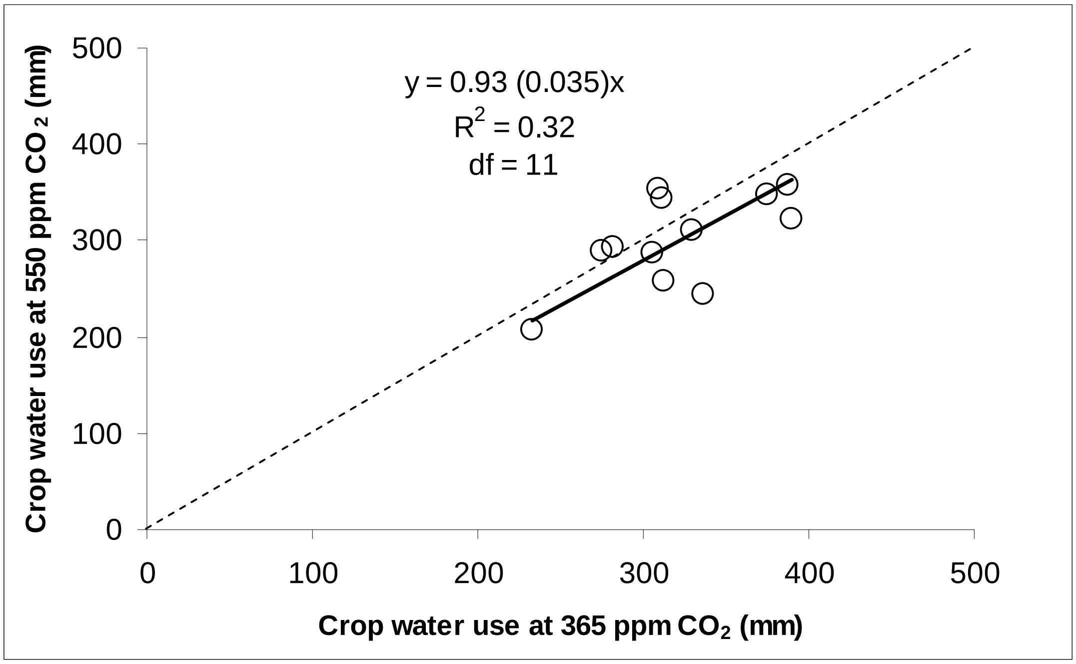

Figure 2. Comparison of water use response under elevated CO_2 compared to daytime ambient conditions (365 ppm) of wheat (cv. yitpi) showing significant ($P<0.10$) mean decrease in water use (7%) against the 1:1 unity dashed line. Standard error of linear coefficient shown in parentheses.

Water use efficiency

Water use efficiency was increase by eCO_2 by 30% ($P<0.05$) (Figure 3). Since this gain was greater than the yield gain of 25%, we conclude that the gain in biomass was partly, but notable, due to a smaller contribution from savings in water use with the primary gain due to increased transpiration efficiency through increased radiation use efficiency and reduced transpiration.

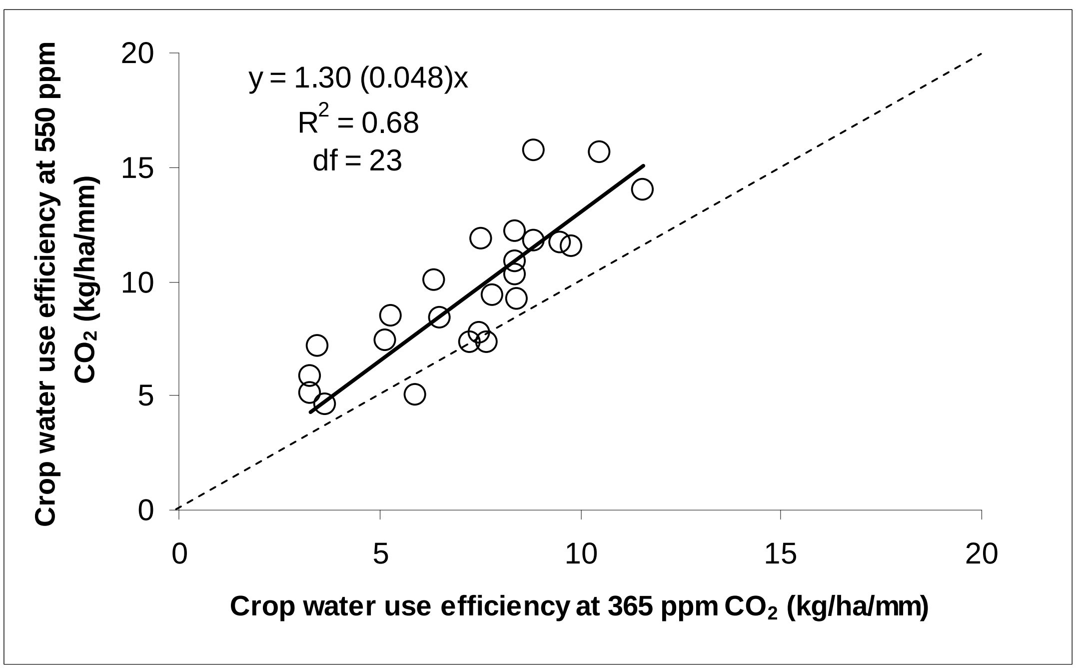

Figure 3. Comparison of water use efficiency response under elevated CO_2 compared to daytime ambient conditions (365 ppm) of wheat (cv. Yitpi) showing significant ($P<0.05$) mean increase in water use efficiency (30%) against the 1:1 unity dashed line. Standard error of linear coefficient shown in parentheses.

Our measurements show a mean increase of 25% in grain yield due to eCO_2. This is partly attributed to water use savings confirmed in Figure 2. Whilst we are yet to analyse radiation use efficiency data and complete our modelling studies our results are encouraging and point to small but useful savings in water use. Whether these savings can offset other negative effects of a warming climate remains to be seen, but these data provide a test bed for a number of models that can extrapolate the likely response of eCO_2 to a different environment.

Conclusions

Grain yield responses to elevated CO_2 were large (mean +25%) and consistent for both above-ground biomass and grain yield. WUE was increased under elevated CO_2 (mean +30%) with evidence of reduced water use (mean 7%) contributing to the increased efficiency. Reduced water use, however, was not universal with no reduction occurring in one year.

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