Future effects of elevated CO_2 on wheat production – an overview of FACE research in Victoria, Australia

Glenn Fitzgerald[1], Rob Norton[2], Michael Tausz[3], Garry O'Leary[1], Saman Seneweera[4], Sabine Posch[4], Mahabubur Mollah[1], Jason Brand1, Roger Armstrong[1], Nicole Mathers[1], Jo Luck[5], Wendy Griffiths[1], Piotr Trebicki[1]

[1] Department of Primary Industries, 110 Natimuk Rd., Private Bag 260, Horsham, Vic, glenn.fitzgerald@dpi.vic.gov.au
[2] International Plant Nutrition Institute, 54 Florence St, Horsham, Victoria, Australia.
[3] Department of Forest and Ecosystem Science, University of Melbourne, Water Street, Creswick, Victoria 3363, Australia.
[4] Department of Agriculture and Food Systems, Melbourne School of Land and Environment, The Melbourne University, Private Bag 260, Horsham, Victoria 3401, Australia.
[5] Department of Primary Industries Victoria, Private Mail Bag 15 Ferntree Gully Delivery Centre, Victoria, Australia.

Abstract

The Australian Grains Free Air CO_2 Enrichment (AGFACE) experiment in Victoria, Australia simulates elevated atmospheric CO_2 (eCO_2) levels expected to occur in 2050. Between 2007-2009 there were 3 physical facilities: (1) the core site at Horsham where measurements were collected on the impacts of irrigation (2 levels), temperature at heading (time of sowing, 2), nitrogen (2 levels) and cultivar (2-8 cultivars) on wheat growth and production under ambient (370 ppm) and elevated (550 ppm) CO_2 levels; (2) Walpeup, in the Mallee, where CO_2 X time of sowing was investigated in a warmer climate and (3) SoilFACE at Horsham where a CO_2 (2 levels) by soil type (3 types) by phase rotation (wheat and field pea) experiment was initiated using intact soil cores. Data showed increased biomass and yield due to eCO_2 with increases of 25-30% for both. In 2009, eight cultivars of wheat were sown to assess cultivar differences. Tillering increases in some cultivars led to increased yields of up to 40%. Although plant N concentration decreased by 4-11%, N uptake increased by 20-60% depending on cultivar and location. Disease severity decreased for stripe rust and increased for crown rot. Soil type was a significant factor for plant biomass and crop N uptake. Modeling results indicate the need for selecting appropriate cultivars adapted to changing rainfall patterns. Beginning in 2010, a field pea - wheat rotation was begun to study the interacting effects of above- and belowground C and N dynamics in the rotation system, including agronomic production, cultivar response and N fixation.

Key Words

AGFACE, FACE, field pea, nitrogen

Introduction

Rising levels of atmospheric CO_2 will cause agricultural production to change dramatically this century. The Australian Grains Free Air CO_2 Enrichment program (AGFACE) seeks to provide knowledge on the effects of elevated CO_2 (eCO_2) on crop production so that the Australian grains industry can develop effective adaptation strategies to climate change. Agricultural productivity will experience both positive and negative impacts depending on a number of interacting factors such as rainfall, temperature, soil processes and crop type/variety. The degree of impact on yield, grain protein and human nutrition from these interacting factors are not well elucidated.

The AGFACE facility is located in Horsham, Victoria, Australia and has finished its 3rd year studying the impacts of eCO_2 on wheat production. It is the only FACE facility to study grains production in the southern hemisphere.

The major objectives include studying crop responses to eCO_2 in order to:

- increase our understanding of future yields, crop water use, crop physiology, plant and soil nitrogen and carbon dynamics so that sound science can be used to develop adaptation policies;
- provide realistic validation data sets for modeling agronomic responses of wheat to increase our confidence in current simulation models to provide adaptation scenarios;
- quantify disease and pest response to eCO_2 and interactions with the crop in order to predict changes to pest and disease severity;
- understand how different crop traits in different cultivars contribute to eCO_2 response to inform plant breeders for development of better-adapted crops.

Knowledge gained will provide policy makers and industry with realistic information based on future atmospheric CO_2 scenarios, rather than with past data or data inferred from laboratory experiments. The multi-factor nature of the experiment will allow a more comprehensive understanding of the interactions inherent in changing climate (water, temperature, nitrogen inputs, CO_2, pests). This knowledge will inform adaptation strategies so that efficient grain production for domestic and export markets is maintained.

It has been recognized internationally that multi-factor experiments will help fill gaps that exist in our knowledge of crop response to increasing CO_2 concentrations. The AGFACE program consists of eight projects or study areas including biological implications of CO_2 distribution within the rings, agronomic responses, trait (cultivar) evaluation, physiological mechanisms, pests and disease dynamics and modeling, belowground processes, simulation modeling and a related *Brassica* “VegeFACE” experiment (not reported).

An overview of the program, results and implications are presented. More specific results are presented in other papers in this conference.

Methods

Although there are various methods to study the response of crops to environmental changes (glasshouses, tunnels, open-top chambers) the FACE methodology is the only way to study crop response under realistic conditions without experimentally imposed artifacts (Hendrey and Miglietta 2006). The lack of walls provides a realistic field situation. Pure CO_2 is injected over the top of the crop through a ring of 8 horizontal tubes (Fig. 1). Wind carries the CO_2 across the canopy and computer control and feedback creates a target centre concentration of 550 ppm, the atmospheric concentration expected in 2050.

Figure 1. FACE ring, 12m diameter.

The AGFACE is a fully replicated design. In 2007-08, interacting impacts of CO_2 (ambient and elevated ~390 and 550 ppm), irrigation (rainfed and supplemental), time of sowing (optimal and late), nitrogen (0 and adequate), and cultivar (Yitpi and Janz) on wheat growth and production were measured in open-air 12 m rings. In 2009, 6 more cultivars were added to expanded rings (16 m diameter) that included cultivars known to differ in tillering, transpiration efficiency and early vigour. Destructive samples were collected at tillering (DC30), anthesis (DC65) and maturity (DC90) and measured for leaf area index (LAI), biomass, yield components, plant & grain N and other attributes. Soil water was measured via neutron access tubes. The size of each sub-plot was about 1.5 by 4 m.

Other experiments have included a 4-m ring design studying eCO_2 by TOS in wheat at Walpeup in the drier Mallee region. And, the related SoilFACE experiment was designed with a phase rotation with wheat and field pea sown in intact soil cores: CO_2 (ambient and elevated) by soil type (calcarosol, chromosol and vertosol) by phase rotation (wheat, pea) by rep (4).

Temperature responses have been studied by locating wheat in two different regions (Mallee and Wimmera) and including two times of sowing to push the later sowing into a warmer time of year. Previous FACE studies in forestry, crops and natural systems have never studied as many interacting effects simultaneously. The AGFACE project has been designed to rigorously address all these interacting factors at the same time.

Results and Discussion

Statistical analysis showed that both wheat biomass and yields increased significantly (25-30%) due to eCO_2, at Horsham and 50-60% at the warmer Walpeup site (3-4 ?C higher day temperatures). Yield responses differed with 10% to 40% increases due to e CO_2 depending on cultivar. Biomass increases are caused by stimulation of photosynthesis by eCO_2 in C3 crops because Rubisco is not saturated by CO_2 at current atmospheric concentrations (Ainsworth et al., 2008). We also showed that different cultivars of wheat have distinct physiological responses to eCO_2 and eCO_2 stimulated tillering on average of 15-20%, which is a major determinant of final yield. Understanding these mechanisms will provide valuable information for selection of genotypes more responsive to eCO_2 (Ainsworth et al., 2008).

Although there were interacting effects for some of the treatment combinations, there were no particular patterns across years, cultivars or locations. However, data analysis is not yet completed.

Crop N concentration decreased in all years by 4 to 11%, depending on cultivar and location. Elevated CO_2 causes inhibition of nitrate assimilation (Bloom et al., 2010), which is hypothesized to decrease nitrate absorption by the plant. This is the likely cause of lower grain protein contents observed and could impact many of the world’s poorest people (Gleadow 2010). Despite the decreased plant and grain N concentrations, total N uptake by the crop increased by about 20% at Horsham and 60% at Walpeup due to the increased biomass. This could have implications on fertiliser inputs, especially since the production, transport and use of these increases greenhouse gas production (Burney et al. 2010). Levels of Zn and Fe were reduced under eCO_2 by about 10% each. Changes in human nutritional qualities would impact people most severely in developing nations where much of the food consumed is plant-based.

It is expected that long term increases of plant and root biomass could lead to increased carbon input to the soils and carbon sequestration as well as progressive nitrogen limitation, leading to immobilisation of nitrogen in the soil, which would require additional nitrogen inputs in the future to maintain productivity. Our results have shown a mixed response (either increase in root biomass or none, depending on season). Other results showed that soil type plays an important role in determining final crop biomass and N uptake.

Despite reported gains in water use efficiency expected from eCO_2 (Leakey et al. 2009), we showed through crop and climate simulation modeling that increases in temperature and changes in rainfall patterns will cause shifts in agricultural production across Victoria, Australia. Areas with reduced rainfall and higher temperatures (e.g., the Mallee) are likely to experience reduced yields, while other areas with adequate rainfall may have increased yields. These results interact with sowing time and variety. Modeling results indicate the need for selecting longer season cultivars adapted to changing rainfall patterns.

Pests and disease dynamics are expected to change due to eCO_2 (Melloy et al. 2010). We have shown that wheat crown rot may become more severe due to eCO_2 but stripe rust may decrease in intensity under drier conditions. A spatial model for the spread of Barley yellow dwarf virus is being developed, integrating crop models, epidemiology and spatial modeling. These results have implications to yields and potentially where crops may be grown profitably. These results can inform crop breeder to focus their research for incorporation of disease resistance.

A wheat-field pea rotation was sown in 2010 and will be rotated each year, providing an opportunity to explore the effects of eCO_2 on a simplified "systems" level (Fig. 2). Various cultivars of wheat and field pea will alternate with uniform (bulk) area of the previous crop. This will allow understanding the effects of eCO_2 on soil nitrogen dynamics (and N fixation) on the subsequent wheat crop on a field scale. This will be important to understanding how to adapt to and compensate for progressive nitrogen limitation – if the nitrogen from the legume ameliorates the loss of available N to the plants then more fertiliser might not be required.

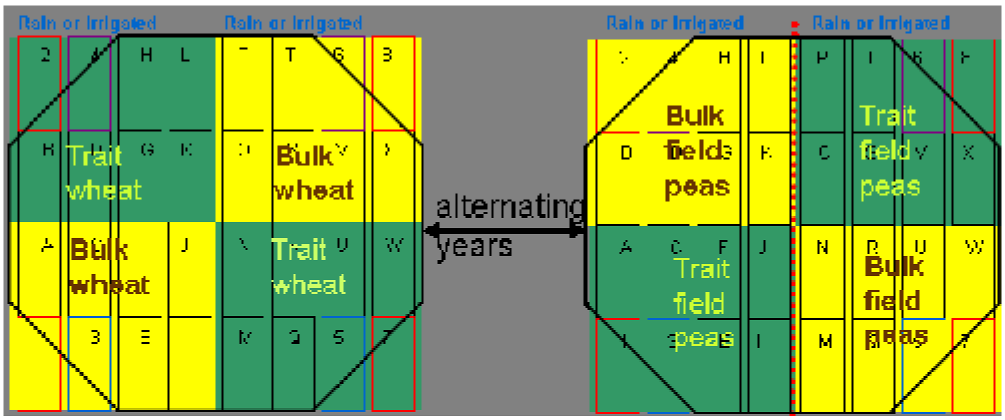

Figure 2. Wheat-field pea rotation in FACE for 2010 and beyond.

Conclusion

Elevated CO_2 causes significant changes in crop physiology, growth, yield, grain quality, pest and disease dynamics and soil processes. These will have perhaps dramatic effects on future cropping systems and human nutrition. As well as filling important gaps in our scientific knowledge, the results of this work will provide sound science on which to base policy decisions to guide the Australian grains industry to adapt to the challenges of climate change. Longer term experiments are required to elucidate questions, such as progressive nitrogen limitation and carbon sequestration and how farming systems will adapt in order to inform industry and policy makers.

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References

Ainsworth EA, Beier C, Calfapietra C, Ceulemans R, Tardifs MD, Farquhar GD, Godbold DL, Hendrey GR, Hickler T, Kaduk J, Karnosky D, Kimball BA, Korner C, Koornneef M, Lafarge T, Leakey ADB, Lewin KF, Long SP, Manderscheid R, McNeil DL, Mies TA, Miglietta F, Morgan JA, Nagy J, Norby RJ, Norton RN, Percy KE, Rogers A, Soussana J-F, Stitt M, Weigel H-J and White J (2008). Next generation of elevated [CO_2] experiments with crops: a critical investment for feeding the future world. Plant, Cell and Environment 31, 1317–1324.

Bloom AJ, Burger M, Rubio-Asensio JS and Asaph BC (2010). Carbon dioxide enrichment inhibits nitrate assimilation in wheat and *Arabidopsis*. Science 238, 899-903.

Burney JA, Davis SJ and Lobell DB (2010). Greenhouse gas mitigation by agricultural intensification. Proceedings of the National Academy of Sciences Early Edition (published online).

Gleadow R (2010). Food security in a warming world. Australian Science, Jan/Feb, 31-33.

Hendrey GR and Miglietta F (2006). FACE technology: Past, present and future. In Ecological Studies, Vol. 187, Managed Ecosystems and CO_2 Case Studies, Processes, and Perspectives. Eds J Hosberger, SP Long, RJ Norby, M Stitt, GR Hendrey and H Blum. pp.15-43, Springer-Verlag, Berlin.

Leakey ABD, Ainsworth EA, Bernacchi CJ, Rogers A, Long SP and Ort DR (2009). Elevated CO_2 effects on plant carbon, nitrogen, and water relations: six important lessons from FACE. Journal of Experimental Botany, 60, 2859–2876.

Melloy P, Hollaway G, Luck J, Norton R, Aitken E and Chakraborty S (2010). Production and fitness of Fusarium pseudograminearum inoculum at elevated carbon dioxide in FACE. Global Change Biology, published online. doi: 10.1111/j.1365-2486.2010.02178.x.