Growth, yield and photosynthetic responses to elevated CO$_2$ in wheat

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Projected climate – 2050

by 2050

1-2°C warmer

50-100 mm drier
Future is unclear for Australian wheat production?

**CO₂ * Temperature * Water**

Crop growth, yield and quality are affected by all these factors.

- To assess the impact of climate change on the wheat industry, need to assess the **interaction** of these three factors.

- Ecosystem and biotic impacts on production systems.

- **Adaptation strategies in response to changing climate**

Modeled impact of climate change on wheat yields in the Victorian Mallee (Grace, 2006)
Effects of elevated CO$_2$

- In C3 plants – CO$_2$ & O$_2$ compete for active sites on ‘RuBisCO’ shift to increase gross photosynthetic C fix and reduce C loss in photorespiration.
- In both C3 and C4 plants, stomatal aperture narrows reducing water use.
- Therefore C↑ increases & W↓ decreases so TE increases.
- Increase in CO$_2$ from 350 ppm to 550 ppm increases TE by 50%.

*This all seems simple and positive*

Ainsworth & Long 2005 New Phytologist
Photosynthetic acclimation to eCO$_2$

Photosynthetic rates increased in response to short term CO$_2$ enrichment.

BUT when exposed to eCO$_2$ for extended periods, photosynthetic rates decline. This process is known as “acclimation”.

Various morphological, biochemical and molecular adjustments.
- Decline in plant N
- RuBisCO content lower
- RuBisCO activation higher
- Increased Tillering

Ecosystem responses eg PNL, pathogens)

Seneweera et al 2005 Journal of Crop Improvement 13-31-52
Australian Grains Free Air Carbon Dioxide Enrichment Facility (FACE)

• Located at Horsham in Western Victoria – 36°S.
• aim to answer the fundamental question of how the supply of N and water interact with higher temperatures under elevated CO₂ in relatively low yield potential situations ie 1 to 4 t/ha

• Experimental treatments
  – FACE CO₂ – ambient (~380 ppm) & 550 ppm
  – Water – rainfed & irrigated (+50 mm)
  – Sowing time – early sown (June 18) & late sown (August 22) – generates +5°C during flowering
  – Nitrogen – low and supplemented – managed in response to water supply (Yitpi only)
  – Cultivar - Yitpi and Janz

4 replicates
Each ring 12 m
16 m in 2009 et seq
Spread over 5 ha site
Central CO₂ Sensor, Wind Speed & Direction

CO₂ Controller

Fumigation tubes

Mean Temperature for the 15 days after anthesis

Seasonal Water Supply (Rain + Supplements)

Above Ground Biomass (g/m²)

- Very few interactions among the main treatments
  - *ie CO₂*TOS*Water*Cultivar
- TOS and water responses followed what would be expected.
- CO₂ increased growth at all stages by 25-30%.
- CO₂ produced more shoots per plant.

<table>
<thead>
<tr>
<th>Year</th>
<th>Stage</th>
<th>aCO₂</th>
<th>eCO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Tillering</td>
<td>73</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Anthesis</td>
<td>490</td>
<td>612</td>
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<tr>
<td></td>
<td>Maturity</td>
<td>656</td>
<td>802</td>
</tr>
<tr>
<td>2008</td>
<td>Tillering</td>
<td>167</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>Anthesis</td>
<td>706</td>
<td>917</td>
</tr>
<tr>
<td></td>
<td>Maturity</td>
<td>760</td>
<td>992</td>
</tr>
<tr>
<td>2009</td>
<td>Tillering</td>
<td>80</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>Anthesis</td>
<td>550</td>
<td>654</td>
</tr>
<tr>
<td></td>
<td>Maturity</td>
<td>551</td>
<td>730</td>
</tr>
</tbody>
</table>

2009 heat wave *+35°C for 2 weeks in November
Grain Yield and Yield Components

- Again, very few interactions among the main treatments
  - no CO₂ response in TOS2 2008
- TOS and water responses followed what would be expected.
- CO₂ increased yield from 2.52 t/ha to 3.22 t/ha (27%)  
- In 2008, HI declined under eCO₂ with TOS2 but not in TOS1
- CO₂ increased kernel weight in 2 of 3 years but not kernel number.

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield</th>
<th>aCO₂</th>
<th>eCO₂</th>
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<tbody>
<tr>
<td>2007</td>
<td>Yield</td>
<td>258</td>
<td>323</td>
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<tr>
<td></td>
<td>SkNO</td>
<td>4.0</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>KNO</td>
<td>25.3</td>
<td>27.3</td>
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<tr>
<td></td>
<td>KWt(mg)</td>
<td>31.3</td>
<td>32.9</td>
</tr>
<tr>
<td>2008</td>
<td>Yield</td>
<td>247</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td>SkNO</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>KNO</td>
<td>17.9</td>
<td>18.3</td>
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<tr>
<td></td>
<td>KWt(mg)</td>
<td>31.1</td>
<td>32.4</td>
</tr>
<tr>
<td>2009</td>
<td>Yield</td>
<td>252</td>
<td>332</td>
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<tr>
<td></td>
<td>SkNO</td>
<td>3.7</td>
<td>4.0</td>
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<td></td>
<td>KNO</td>
<td>31.4</td>
<td>33.1</td>
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<tr>
<td></td>
<td>KWt(mg)</td>
<td>22.9</td>
<td>24.3</td>
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</table>
Root growth @ Anthesis
(mean of both sowing times and water treatments)

Root Dry Weights to 100 cm

\[ aCO_2 = 587 \pm 52 \, g/m^2 \cdot 12\% \text{ of tops} \]

\[ eCO_2 = 860 \pm 52 \, g/m^2 \cdot 14\% \text{ of tops} \]
### Effects of eCO$_2$ on growth & N demand (2008 data)

<table>
<thead>
<tr>
<th>Factor</th>
<th>[CO$_2$] ($\mu$mol/mol)</th>
<th>GS30</th>
<th>GS65</th>
<th>GS90</th>
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<tbody>
<tr>
<td>Plant N (%)</td>
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<td></td>
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<tr>
<td>550</td>
<td>3.69</td>
<td>1.90</td>
<td>1.56</td>
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<tr>
<td>-5%</td>
<td>380</td>
<td>3.77</td>
<td>2.05</td>
<td>1.63</td>
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<tr>
<td>N Uptake (g/m$^2$)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>550</td>
<td>7.47</td>
<td>17.24</td>
<td>15.73</td>
<td></td>
</tr>
<tr>
<td>+23%</td>
<td>380</td>
<td>6.11</td>
<td>14.28</td>
<td>12.73</td>
</tr>
<tr>
<td>Kernel N%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>550</td>
<td>3.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-3%</td>
<td>380</td>
<td>3.15</td>
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</tbody>
</table>

Similar response in all 3 years

Evidence of acclimation

Decline in grain protein content of ~1% in each experiment

Changes in quality and mineral content (on-going study).

Yitpi & Janz did not show significantly different responses to eCO$_2$
Modeling of Impacts - Upscaling

No Adaptation
Adaptation - Cultivar Differences

• Literature
  – Indeterminate types more responsive (soy, wheat)
  – N fixing more responsive
  – Vigorous more responsive
  – NR’ase implicated in acclimation

• Ziska compared an “old” & “new” cultivar in OTC’s

• Concluded that responsiveness to eCO₂ is related to “indeterminacy” i.e. the ability to set added heads/seed sites.
Cultivar Effects

• Yitpi v Janz
  – Very little difference in response to eCO$_2$
  – Some canopy differences early, but otherwise nothing

• 2008/2009
  – Glasshouse responses of a range of cultivars – Tillering & Photosynthetic responses

• 2009 - look at a wider set of cultivars – traits
  – Widely Adapted (Kauz Dwarf = Zebu); TE differences (Hartog, Drysdale) High grain number (Silverstar); Low Tillering (H45); Current best adapted (AGT Gladius)
Shoot Numbers under eCO$_2$

No significant interaction between shoot number and eCO$_2$

But – the change in shoot number was most for mid-tillering types.
Growth response of 8 cultivars to eCO$_2$

- In the FACE experiment – biomass at maturity
- Significant interaction between CO$_2$ and cultivar
- Zebu was most responsive to eCO$_2$ +59%. Hartog least responsive +11%
Yield response of 8 cultivars to eCO$_2$

- In the FACE experiment – compromised by heat wave during grain filling.
- No interaction between cultivar and CO$_2$
- BUT – some cultivars (eg Gladius, Zebu) appeared to have a larger response than others (eg Hartog, H45, Silverstar)
Kernel weight

- Significant interaction among the cultivars for kernel weights – interaction was for CO₂*Irr*Cultivar
- Silverstar (high “sink”) did increase kernel weight with eCO₂ under rainfed, but not under irrigation. H45 (low “sink”) did not.
- Reflect a variation in the degree of sink limitation?
Summary

- Increase in biomass and grain yield ~ 25% with CO$_2$ @ 550 ppm.
- Less response with hotter conditions (later sowing).
- No particular yield component stands out – they are indicators of the path not the destination.
- Grain protein contents were lower under eCO$_2$.
- Little evidence of differences between Janz and Yitpi – these types are still sink – not source – limited.
- Some evidence of differential response among cultivars – maybe high growth rates, low determinacy, (high NUE?).
- Seek future types that are less sink limited and with lower acclimation response.
Acknowledgements

Grains Research & Development Corp.
Department of Agriculture, Fisheries and Forestry
Victorian Dept. Primary Industries
Australian Dept. Ag, Fisheries & Forestry
Australian Dept. Climate Change
The University of Melbourne

IPNI and the IPNI Global Wheat Group for support to attend this conference.

http://www.ipni.net