Food for thought: crop responses to climate change

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1) How will rising CO₂ contribute to climate change impacts on crop production in the 21st century?

2) How can we improve the situation?
Climate change is multifaceted

- CO₂
- °C
- flooding
- drought
% change in crop yields in 2080 considering altered temperature, rainfall and socio-economics but NO carbon dioxide fertilization of plant growth

Map 1

Without carbon fertilization

If there are no beneficial effects from increased carbon dioxide, agricultural output declines almost everywhere and catastrophically closer to the equator.

(climate-induced percent change in agricultural productivity between 2003 and the 2080s)

Source: Cline (2007).
Note: NA refers to “not applicable” for Alaska and northern Canada, and to “not available” elsewhere.
Climate change is multifaceted

- CO₂
- °C
- flooding
- drought
% change in crop yields in 2080 considering altered temperature, rainfall and socio-economics PLUS carbon dioxide fertilization of plant growth

Map 2

With carbon fertilization

If some crops benefit from increased carbon dioxide, the global impact is less dire and those areas farther from the equator may see some increases in agricultural productivity.

(climate-induced percent change in agricultural productivity between 2003 and the 2080s)

Source: Cline (2007).
Note: NA refers to “not applicable” for Alaska and northern Canada, and to “not available” elsewhere.
And…

So our ability to feed everyone will be challenged like never before.
The impacts of CO$_2$ on crops have only been fully appreciated in the last 30 years.

Also...

Unlike temperature and precipitation, there are not consistent spatial and temporal patterns of CO$_2$ that can be studied and used to develop improved crops.
Soybean Free Air gas Concentration Enrichment Facility (SoyFACE)

www.soyface.illinois.edu
20 meters
We use this facility to understand how plants respond to elevated CO$_2$. This is the first step in crop improvement.
Photosynthetic responses to rising CO$_2$

**C$_3$ crops**

**Soybean**

- 20% gain in 2050

**Wheat**

**C$_4$ crops**

**Maize**

- No gain
Photosynthesis

$\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{sugars}$

growth

yield
Benefits to $C_3$ and $C_4$ crops

Today’s $[CO_2]$
Leaf curling

2050’s $[CO_2]$
No leaf curling
Theory A: Biomass Yield

% Increase at elevated $[\text{CO}_2]$:

- Photosynthesis
- Biomass
- Yield

Soybean vs. Wheat
Food for Thought: Lower-Than-Expected Crop Yield Stimulation with Rising CO₂ Concentrations

Stephen P. Long,¹,²,³ Elizabeth A. Ainsworth,⁴,¹,³ Andrew D. B. Leakey,⁵,¹ Josef Nösberger,⁵ Donald R. Ort⁴,¹,²,³

A

- Soybean
- Wheat
No change in development, growth or yield under well watered conditions

Leakey (2009) *Proceedings of the Royal Society*
C₄ species dominate some of the most food insecure regions, but no data from such places.

Figure 1. Percentage of agricultural land used for the production of C₄ crops in 2006. Estimates of national C₄ crop production area were taken from the ProdSTAT database, FAO (http://faostat.fao.org) (grey, n.a.; white, 0–20%; yellow, 20–40%; orange, 40–60%; red, 60–80%; dark red, +80%).
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Climate change is multifaceted

Two options for crop improvement:
- Reduce the negative
- Enhance the positive
Temperatures, drought & flooding have always challenged agriculture.

Decades of research and plant breeding have dealt with these stresses.

Biotechnological approaches are now making further progress.

But we have made no attempt to take greater advantage of rising CO$_2$. 
Theory A' Biomass Yield

% Increase at elevated [CO₂]

Observations across all C3 FACE experiments

Room for improvement

Observations across all C3 FACE experiments
More mitochondria allow the cells in leaves to produce more energy to transport sugars to where they are needed for growth or yield.

We have identified over 600 genes whose expression is altered by growth at elevated CO$_2$.

We are testing which genes might be manipulated to improve the yield of crops at future CO$_2$ concentrations.
1) How will rising CO$_2$ contribute to climate change impacts on crop production in the 21$^{st}$ century?

2) How can we improve the situation?

1a) Elevated CO$_2$ will benefit C$_3$ crops, but maybe not as much as currently assumed.

1b) C$_4$ crops will benefit much less.

2) The benefits of rising CO$_2$ to crops are not fully realized and could be improved.
www.igb.uiuc.edu/research/ecology_globalchange.html

Genomic Ecology of Global Change

- Researchers
- Problem
- Research
- Benefits
- Early Successes

Genomic Ecology of Global Change Video - Donald Ort (DivX Player Needed, download here)

Researchers

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