


Farms of the Future: N & P Contents of Soybean Tissues in a High- CO_2, High-O_3 World

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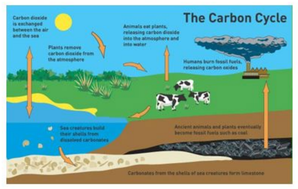
SoyFACE

ABSTRACT

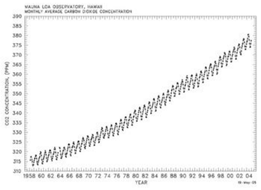
Atmospheric CO_2 is predicted to increase from current levels of 375 ppm to 550 ppm by 2050. Atmospheric ozone (O_3) is also increasing. Increases in these atmospheric gases can have profound impacts on the growth and productivity of crop plants: CO_2 through its direct impacts on photosynthesis and plant water use, and O_3 through its direct negative impacts on photosynthesis. Further, tissue chemical composition may be affected through altered rates of resource accrual or allocation. Here we report data on effects of increased levels of CO_2 and O_3 on tissue N & P contents in soybeans from a large-scale, multi-investigator FACE study. We monitored biweekly growth and seed yield for field-grown soybean crops exposed to current and future-predicted atmospheres of CO_2 and/or O_3 for three consecutive years (2004 - 2006) and assessed tissue chemistry on a monthly basis for 2004. We evaluated tissue N & P contents of soybean roots, stems, leaves, pods, seeds and leaf litter for field-grown soybean crops exposed to current and future-predicted atmospheres of CO_2 and/or O_3. Increased CO_2 availability resulted in increased aboveground net productivity and seed yield. In contrast, in 2005, elevated O_3 reduced soybean productivity and seed yield, but elevated CO_2 ameliorated this response. In addition, soybeans grown at elevated O_3 levels produced smaller seeds. Overall, these results suggest that soybean crops exposed to high levels of O_3 may experience reduced productivity and yield, but that elevated CO_2 may reduce these negative impacts.

INTRODUCTION

- Burning of fossil fuels, land use changes has lead to a 30% ↑ in $[CO_2]$


- Intergovernmental Panel on Climate Change (IPCC) predicts further $[CO_2]$ ↑ by 50%
- Effects of ↑ $[CO_2]$
  - Increase in leaf area and photosynthesis
  - Increase in dry mass
- Increase in air pollutant concentrations has led to a doubling of tropospheric $[O_3]$ within the last century
- Surface $[O_3]$ reaches a daily peak of 60 ppb during the growing season and predicted to increase over next 50 years
- Effects of ↑ $[O_3]$
  - Premature leaf senescence
  - Decreased light interception, chlorophyll, photosynthesis
  - Reduction of assimilate availability, alterations in assimilate partitioning



- A review of studies showed that a doubling CO_2 in enclosed environments increased the yield of C_3 crops (like soybean) by an average of 33% (Kimball, 1983).

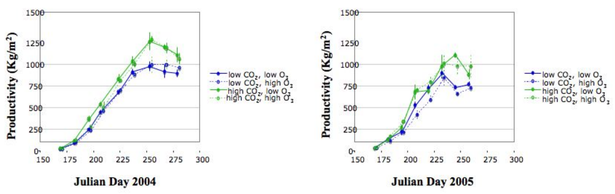


Figure 1: Total aboveground productivity (Kg/m^2) of soybeans grown under ambient (370ppm) and elevated (550ppm) atmospheric CO_2 and ambient (no addition) vs. elevated (20% above the daily value) atmospheric O_3 during the 2004 growing season. Data are in means of ± standard errors of n=4.

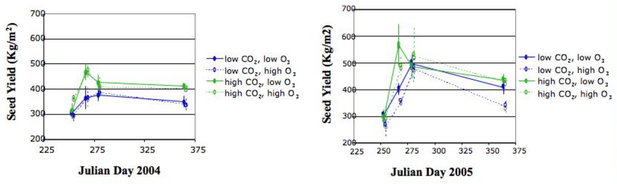


Figure 2: Total seed yield of soybeans grown under ambient (370ppm) and elevated (550ppm) atmospheric CO_2 and ambient (no addition) vs. elevated (20% above the daily value) atmospheric O_3 during the 2004 growing season. Data are in means of ± standard errors of n=4.

- Our results show a 20% increase in growth and a 28% increase in final seed yield for soybeans plants grown at elevated CO_2 in 2004 with similar trends occurring in 2005 and 2006.
- In 2004 elevated O_3 had no affect on productivity and seed yield (a year in which O_3 levels were modest at SoyFACE), but in 2005 elevated O_3 reduced soybean productivity and seed yield, although elevated CO_2 ameliorated this response.

- The soybean-corn agro-ecosystem is one of the largest single ecosystem types in the US
- Studying the effects of climate change on soybeans will help us better understand future food security

HYPOTHESES

Increased atmospheric levels of CO_2 will increase %N and %P in soybean tissues.

Increased atmospheric levels of O_3 will decrease %N and %P in soybean tissues.

METHODS

Site description
- South Farms, University of Illinois at Urbana-Champaign
- Soy FACE (Soybean Free Air Concentration Enrichment)
  - Treatments (16 total rings)
  - Control - current ambient CO_2 of 370ppm, no added O_3
  - Elevated CO_2 to a target of 550ppm
  - Elevated O_3 to a level 20% above the daily value
  - Elevated CO_2 and elevated O_3
- Rings - enclosed by tubing for gas release, 70 ft in diameter
- Weather stations control release of gases

Harvesting
- Biweekly, 1 meter subplots randomly chosen from each ring
- Plants separated into stems, leaves, and pods
- Litter samples collected
- Samples forced-air oven dried at 65ºC
- Tissue biomass and average seeds per pod determined
- Root tissue was collected by Argonne National Laboratory



Weather Station

Tissue Analysis

C and N via combustion
- Tissues ground using a Cyclotec 1093 sample mill
- 3-4 mg samples measured with a Mettler Toledo AT21 Comparator
- Carbon and nitrogen contents analyzed on a CE Instruments Flash 1112 Series EA ThermoQuest NC Soil Analyzer

N and P via digestion
- Dried ground tissues sent to the Kansas State University Soil Testing Lab
- Digested plant material from either a sulfuric acid/hydrogen peroxide digest or a salicylic-sulfuric digest was analyzed simultaneously using the Technicon AAII auto analyzer with the colorimetric Industrial Method 334-74W/B using separate channels.

Data Analysis

3-way ANOVA with main effects of harvest date, CO_2 and O_3. All main effects and interactions were tested over the residual error term.

RESULTS

Mass Component	Effect of Elevated CO_2	Effect of Elevated O_3	Interactions between CO_2 and O_3
Leaf Mass (g/m^2)	Increase	None	None
Stem Mass (g/m^2)	Increase	None	None
Reproductive Mass (g/m^2)	Increase	None	None
Seed Yield (g/m^2)	Increase	None	None
Cumulative Litter Production (g/m^2)	Increase	None	O_3 increases at low CO_2, O_3 decreases at high CO_2
Leaf N (%)	Decrease	None	None
Leaf P (%)	Decrease	None	None
Total Aboveground Productivity (g/m^2)	Increase	None	None

Table 1. Selected growth responses for soybeans in elevated CO_2 (550ppm), elevated O_3 (20% greater than daily value), and elevated CO_2 plus elevated O_3 harvested from south farms at University of Illinois, Urbana-Champaign, IL

Tissues	Analysis	Effect of Elevated CO_2	Effect of Elevated O_3	Interactions between CO_2 and O_3
Leaves[a]	% N (digestion)	None	None	None
	% P (digestion)	None	None	None
	% N (combustion)	None	**Increase**	None
Pod Walls[b]	% N (digestion)	None	None	None
	% P (digestion)	None	None	**Decrease**
	% N (combustion)	None	None	None
Fine Roots[a, b]	% N (digestion)	None	None	None
	% P (digestion)	None	None	**Decrease (early harvest)**
	% N (combustion)	None	None	None
Litter[a, b]	% N (digestion)	None	None	None
	% P (digestion)	None	None	None
	% N (combustion)	None	**Increase**	None
Stems[a, b], Seeds and Pods[a], Seeds[b], Tap Roots[a, b]	% N (digestion)	None	None	None
	% P (digestion)	None	None	None
	% N (combustion)	None	None	None

[a] – Tissues harvested on 8/25/2004
[b] – Tissues harvested on 9/22/2004

Table 2. %N (digestion and combustion derived) and %P in soybean tissues growing under elevated CO_2 (550 ppm), elevated O_3 (20% > daily value), and elevated CO_2 plus elevated O_3 harvest from south farms at University of Illinois, Urbana-Champaign, IL

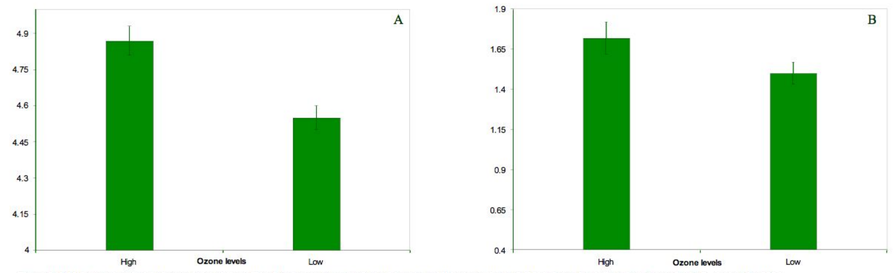


Figure 3: %N (by combustion) in leaves (A) and litter (B) of soybeans grown under ambient (no addition) vs. elevated (20% above the daily value) atmospheric O_3 during the 2004 growing season. Data are in means of ± standard errors of n=8 and 16 respectively.

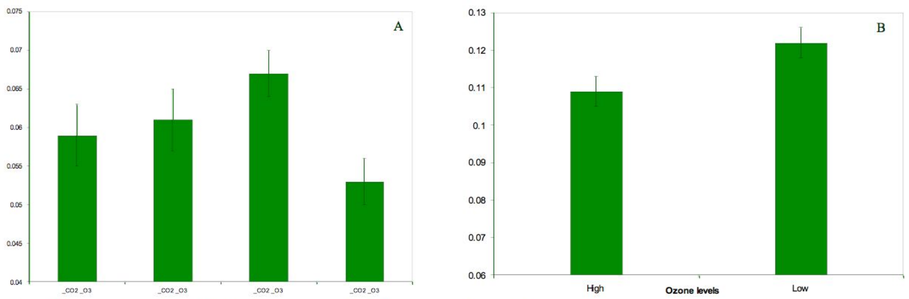


Figure 4: % P in pod walls (A) and fine roots (B) of soybeans grown under ambient (370ppm) and elevated (550ppm) atmospheric CO_2 vs. ambient (no addition) vs. elevated (20% above the daily value) atmospheric O_3 for harvest date 8/25/2004 during the 2004 growing season. Data are in means of ± standard errors of 4 and 8 respectively.

DISCUSSION

- Despite increase in seed yield and plant biomass that occurred in 2004 high CO_2 treatments, no affect was observed on %N and %P in tissues. N and P uptake was commensurate with carbon accrual. Either these nutrients are not limited in these fertilized agricultural fields, or the plants are able to continue to uptake (or utilize symbiotically-fixed N via the production of root nodules) these nutrients commensurate with growth demands.
- Litter and leaves grown at high O_3 had higher %N when combustion was used to derive N, however no affect was seen on N derived from the Kjeldahl method. A study comparing combustion to the Kjeldahl method found that combustion gave significantly higher N values (Daun and DeClerq). Our results indicate that the differences between these methods are enough to affect whether or not data is deemed significant. The greater sensitivity of the combustion method is required to fully determine how tissue level N has been affected by increased O_3.
- Fine roots had reduced %P in elevated O_3 at an early harvest date, however results from a later harvest date showed no change in %P.
- Pod walls had reduced %P when both O_3 and CO_2 were elevated.
- These reductions of %P at elevated O_3 may be a result of slight compensations being made in less essential tissues (fine roots, pod walls) to ensure necessary nutrients are available to tissues essential to growth and development (seeds, leaves, stems). Compensation could explain why no changes in %P occurred at elevated O_3 in seeds, leaves, and stems even though size and yield of these tissues did decrease.

CONCLUSIONS

❖ Elevated CO_2 did not affect %N and %P in soybean tissues.

❖ Elevated O_3 lead to an increase in leaf and litter %N and a decrease in fine root and pod wall %P.

❖ N and P tissue levels are not affected by elevated CO_2 and O_3 in the same way as biomass and seed yield.

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