

# Ozone Research and Vegetative Impacts

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**and**

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**Mechanisms of Plant Responses to Ozone in the Northeastern U.S.**

# Ozone Formation

- Ozone is formed in the atmosphere when its precursors (volatile organic compounds, nitrogen oxides and carbon monoxide) generated mainly from fossil fuel combustion react with oxygen in the presence of sunlight.
- Natural vegetation, however, is a source of VOC emissions and has significant influences on regional atmospheric chemistry.
- The ozone concentration in the lower atmosphere includes two components, a background level of ozone (tropospheric ozone) and ozone formed during local air pollution events in the planetary boundary layer.

# Ozone Levels

- Ozone is not limited to urban areas because ozone and its precursors can be transported hundreds of miles into rural areas where agricultural activities occur.
- Efforts to reduce pollution emissions have lowered peak concentrations in the U.S., but ozone levels remain high enough to impact crops and forests in many regions of the U.S.
- There is a concern that future reductions in local ozone formation will be offset by rising background levels as global industrialization increases.

# Ozone Injury to Vegetation



Symptoms of ambient ozone injury

- Ozone effects on plants are initiated in leaves when the gas enters through the stomates and disrupts cellular processes, resulting in suppression of growth and yield of many crops. Non-stomatal ozone deposition may be large, but its phytotoxic effects are likely small although effects on epicuticular wax and subsequent interactions between leaves and the atmosphere are unknown.

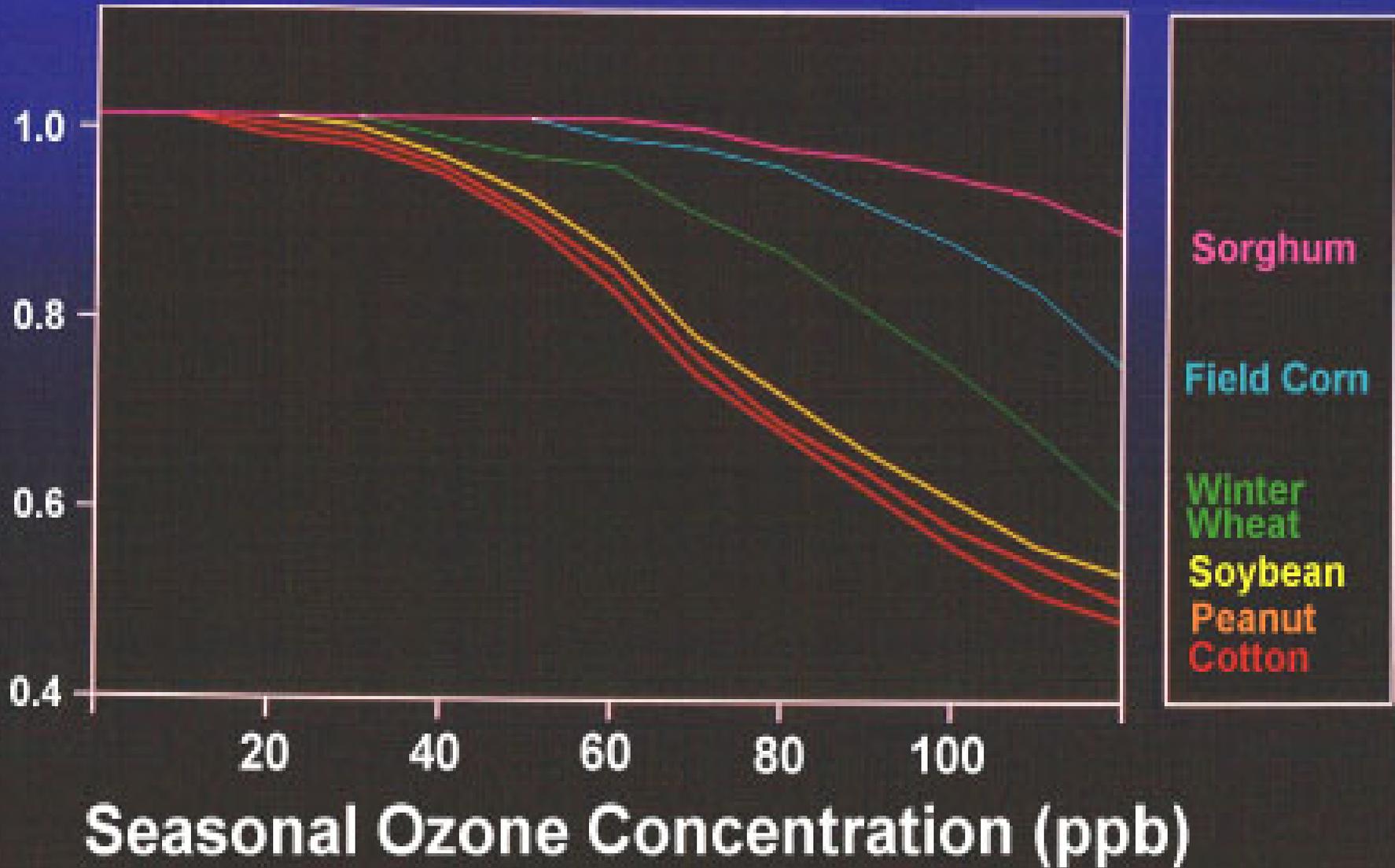
# Mechanisms

- Ozone impairs growth primarily by inhibiting net photosynthesis and perhaps translocation processes, which limit availability of photosynthate needed for biomass production. It is clear that ozone results in lower carbon fixation due to inhibition of ribulose biphosphate carboxylase (Rubisco) activity in the chloroplasts of leaves.
- Allocation of carbon and energy resources to detoxification and repair processes in ozone-stressed plants likely detracts from growth as well.
- With less carbon availability, plants produce fewer branches, leaves, roots, flowers and fruit.
- Ozone exposure also accelerates plant senescence, reduces leaf longevity, decreases water use efficiency, and inhibits pollen tube growth.

# Ozone Impacts on Crop Yield

- Current ground-level ozone concentrations in many regions of the U.S. can suppress yields of sensitive crops by 5 - 15%, with greater impacts expected if ozone levels continue to rise. Some of the most productive agricultural areas in the U.S. are exposed to elevated ozone (Northeast, Mid-Atlantic, Southeast, Midwest, eastern Central Plains, east Texas, central California).
- Sensitive crops include soybean, cotton, peanut, clover, alfalfa, rice, and wheat. (and tobacco). Many fruit and vegetable crops such as tomato, bean, grape, watermelon, and potato are ozone sensitive. Some fruit trees exhibit foliar injury due to ozone.
- In California, ozone-caused yield losses were highest in cantaloupe, grape, cotton, orange, onion, and bean, where losses were projected to range from 12 to 31%. For these crops, which are grown primarily in the San Joaquin Valley and southern California, reductions in yield may largely be due to the high ozone exposures that occur during the summer growing season.
- Projected yield losses due to ozone were less severe in lemon, alfalfa, wheat, corn, processing tomato, rice, and silage, where losses ranged from 3 to 9%. (California EPA 1997).

# Proportional Yield Response



Heagle, A.S. 1989. Ozone and crop yield. Annual Review of Phytopathology 27:397-423.

# Ozone Experiments



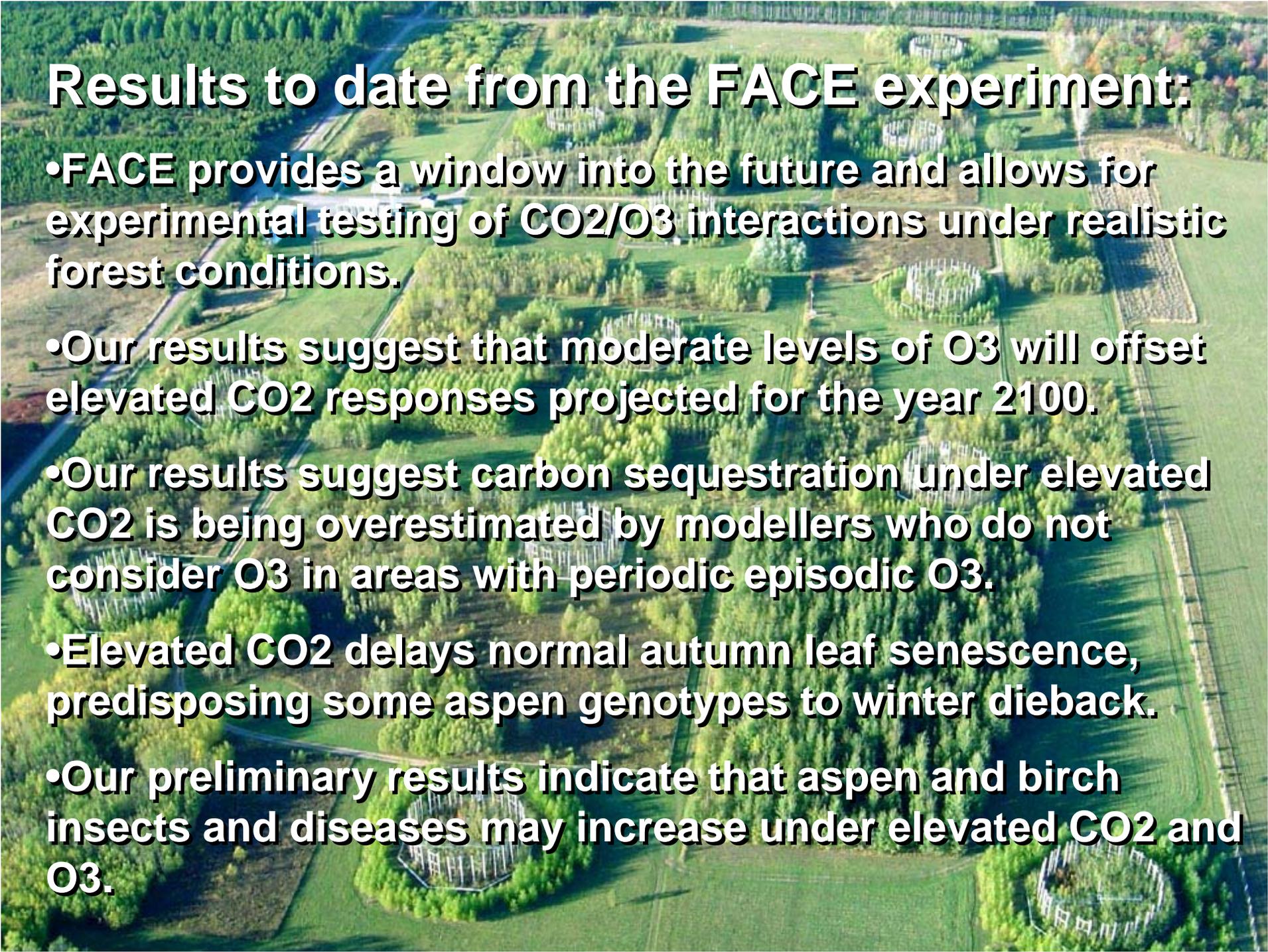
Controlled environment chambers for ozone treatments



Open top field chamber for ozone treatment of plants

**The Aspen FACE (Free-Air Carbon Dioxide Enrichment) Experiment is a multidisciplinary study to assess the effects of increasing tropospheric ozone and carbon dioxide levels on the structure and function of northern forest ecosystems**





## **Results to date from the FACE experiment:**

- **FACE provides a window into the future and allows for experimental testing of CO<sub>2</sub>/O<sub>3</sub> interactions under realistic forest conditions.**
- **Our results suggest that moderate levels of O<sub>3</sub> will offset elevated CO<sub>2</sub> responses projected for the year 2100.**
- **Our results suggest carbon sequestration under elevated CO<sub>2</sub> is being overestimated by modellers who do not consider O<sub>3</sub> in areas with periodic episodic O<sub>3</sub>.**
- **Elevated CO<sub>2</sub> delays normal autumn leaf senescence, predisposing some aspen genotypes to winter dieback.**
- **Our preliminary results indicate that aspen and birch insects and diseases may increase under elevated CO<sub>2</sub> and O<sub>3</sub>.**

**SoyFACE (Soybean Free Air Concentration Enrichment) is an innovative facility for growing crops under production field conditions in an atmosphere that is anticipated for the middle of this century, namely one with higher levels of carbon dioxide and ozone.**



<http://www.soyface.uiuc.edu/index.htm>

# Midwest Ozone Concentrations

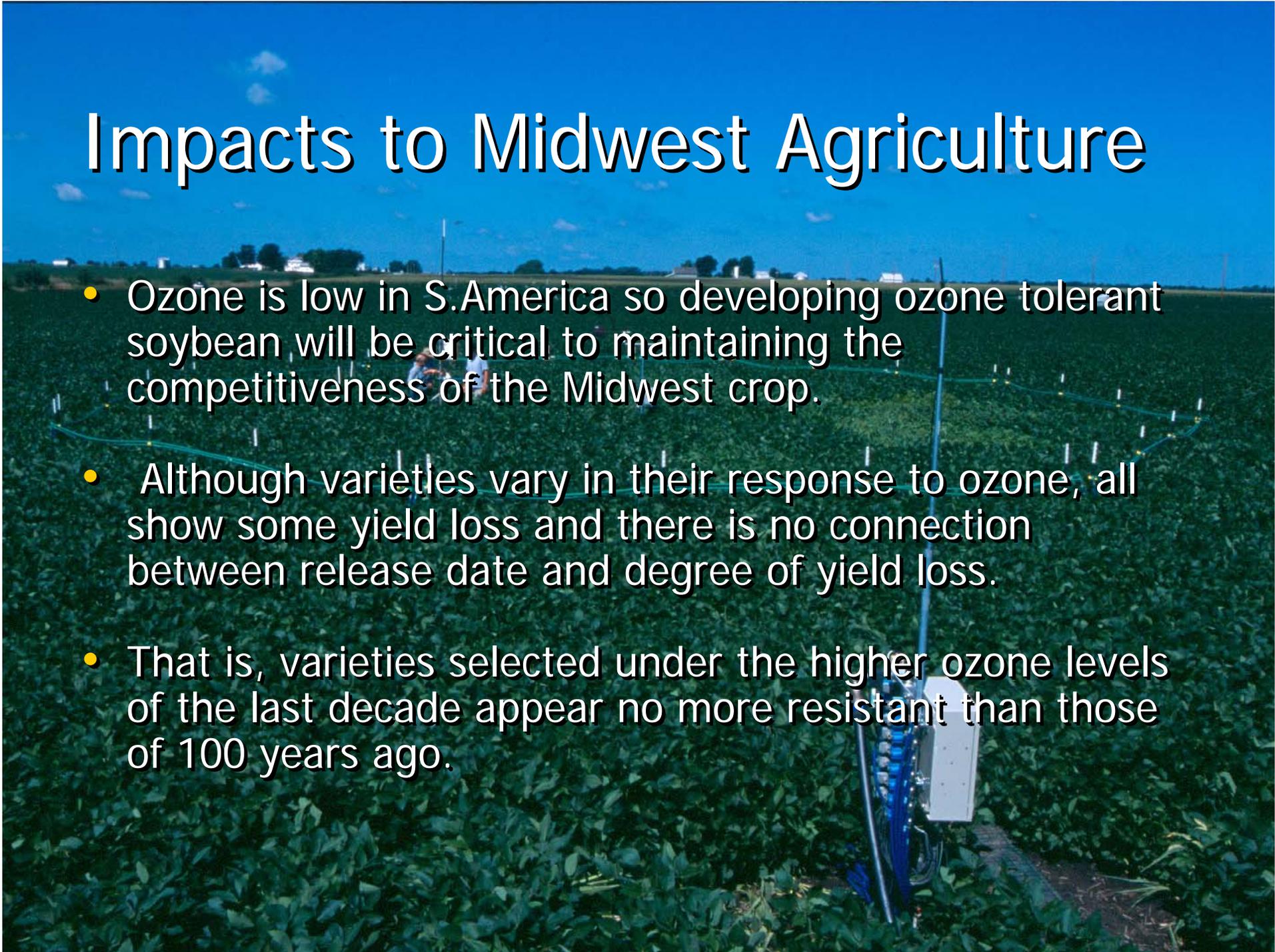
- The air pollutant ozone has risen steadily in the rural Midwest since the 1960s. Daytime summer concentrations in central Illinois average 50 – 60 parts per billion (ppb).
- Soybean is one of the most sensitive crops to ozone, showing yield decreases when levels exceed 30 ppb.
- Studies in chambers suggest that current levels in Illinois lower soybean yields by about 10%.
- However, until now this has not been tested in fields in the open air. SoyFACE has provided the first “real-world” test of these losses.

# Reduced Yields in Soybean

- The facility raises the ozone level, 20% background, from planting to harvest.
- In 2002 the background daytime ozone concentration was 60 ppb, the current average for Central Illinois, and an increase to 72 ppb, the mean level expected for 2030 – 2050, decreased yield by 15%. This not only confirms the expectation from chamber studies of a yield loss, but shows even more damage.
- In 2003 mean ozone concentration was low at 50 ppb. Increasing this by 20% raised the concentration to the 60 ppb, the average typical of Central Illinois summers today, and lowered yield by 25%.
- 2003, as a low ozone year, showed the yield loss that the crop suffers in an average year today while 2002 showed the further loss that will occur, if we do not find a solution.

# Impacts to Midwest Agriculture

- Ozone is low in S.America so developing ozone tolerant soybean will be critical to maintaining the competitiveness of the Midwest crop.
- Although varieties vary in their response to ozone, all show some yield loss and there is no connection between release date and degree of yield loss.
- That is, varieties selected under the higher ozone levels of the last decade appear no more resistant than those of 100 years ago.



# More Research Results

- Through collaborative research between Minnesota and Alberta scientists, in a chamber-less, natural field exposure study in Alberta, ambient air quality and meteorological factors accounted for two-thirds of the variability in alfalfa yield; air quality influenced half of the accounted variation, with ozone alone accounting for 25%.

# More Research Results

- Based on increased deposition and lignification of cell-wall constituents in a number of common grassland species, loss of nutritive quality to mammalian herbivores due to ozone injury can be expected to approach the same order of magnitude as that observed for biomass yield depression. This is important because total loss of consumable food value (fractional reduction in yield  $\times$  fractional reduction in nutritive quality for herbivores) can be much more significant than biomass yield reductions alone in the assessment of the true economic impact of ozone on herbaceous vegetation under current and future global-climate scenarios. (Muntifering & Chappelka 2006).
- Elucidation of causal relationships between ambient air quality, crop yield and nutritive quality represents a novel application of air pollution research to forage-based animal production systems.

# More Research Results

- Increases in atmospheric carbon dioxide tend to ameliorate ozone injury. Elevated carbon dioxide and ozone pollution interact to affect crop yields, suggesting that projected benefits of rising carbon dioxide in the atmosphere are overly optimistic and are based on conceptual models that are too simplistic.
- Ambient levels of ozone in many national parks are currently high enough to cause visible foliar injury on a wide range of native plant species. These parks include Acadia National Park, Shenandoah National Park, Great Smoky Mountain National Park, Rocky Mountain National Park, Sequoia and Kings Canyon National Parks, and Yosemite National Park. Some plants with foliar injury have been shown to have physiological dysfunction, for example altered stomatal conductances and water use.

# Agroecosystem Response

- The quantitative evidence linking specific ozone concentrations to specific vegetation effects — especially at the complex ecosystem level must continue to be characterized as having high uncertainties due to the lack of data for verification of those relationships. (CASAC 2006).
- To a large extent, this is an unavoidable consequence of the inherent complexities of ecosystem structure and function, interactions among biotic and abiotic stressors and stimuli, variability among species and genotype, detoxification and compensatory mechanisms.
- Nevertheless, the compelling weight of evidence results from the convergence of results from many various and disparate assessment methods including chamber and free air exposure, crop yield and tree seedling biomass experimental studies, foliar injury data from biomonitoring plots, and modeled mature tree growth.

# CASAC Recommendation

- CASAC unanimously agrees that it is not appropriate to try to protect vegetation from the substantial, known or anticipated, direct and/or indirect, adverse effects of ambient ozone by continuing to promulgate identical primary and secondary standards for ozone. Moreover, the members of the Committee and a substantial majority of the Ozone Panel agrees with EPA staff conclusions and encourages the Administrator to establish an alternative cumulative secondary standard for ozone and related photochemical oxidants that is distinctly different in averaging time, form and level from the currently existing or potentially revised 8-hour primary standard. (CASAC, 2006

<http://www.epa.gov/sab/pdf/casac-07-001.pdf>)

# Economic Impact

- Although the actual economic costs of ozone-induced crop losses are difficult to assess, the total benefits resulting from various regulatory scenarios, mostly involving reductions of current ambient levels, range from about 0.1 to 2.5 \$billion (1980 US dollars) in the U.S.
- The U.S. EPA 1996 ozone criteria document estimated national level losses to major crops to be in excess of 1 \$billion (1990 US dollars). Other studies estimate benefits of 2 – 3.3 \$billion in the U.S. by eliminating ozone precursors from motor vehicle emissions.
- Due to the non-linear shape of many crop-ozone dose-response curves, we might expect a disproportionately larger effect for each unit increase in global average ozone concentrations.

# Future Direction

- Plant varieties can be bred to tolerate increased ozone, so genetics may provide an answer to the problem in the form of ozone-tolerant crops should worse case scenarios come to pass. We have demonstrated cultivar variation in ozone sensitivity for a number of crops, evidence that genetic approaches can be employed to develop new varieties with improved ozone tolerance.



# Future Direction

- The past decade has seen substantial progress in interpreting the effects of ozone on plants and the mechanisms by which those effects are mediated. However there is much to be done in a practical sense before that information can be translated into useful products.