FREE AIR OZONE CONCENTRATION ENRICHMENT OF A SOYBEAN CROP

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INTRODUCTION

Tropospheric ozone concentrations in Illinois (Fig. 1) can greatly exceed the threshold for damage to a soybean crop. In 2002, the daily peak ozone concentration was 73 ppb, causing a yield loss of approximately 20% (Fig. 2). Based on the Intergovernmental Panel on Climate Change assessment of future atmospheric ozone levels, there could potentially be decreased of 35% by the year 2050. A prototype system for controlled release of ozone was developed to allow studies on the possible effects projected levels of ozone could have on soybean crop yields. This ozone release system is based on the high pressure gas jets design currently used for CO_2 fumigation (Miglietta et al.) at SoyFACE. Sixteen experimental fumigation rings of 20 meters in diameter were built in a soybean field as described below.

Figure 1. Source: U.S. EPA.

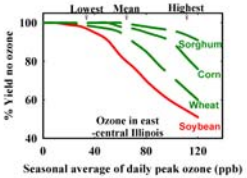

Figure 2. Source: NC State Air Quality Program.

METHODS

Free Air gas Concentration Enrichment (FACE) technology processes information from various sensors inside a fumigation ring to regulate gas concentration increases through a series of control feedback loops. A computer control system (Z-World Inc., Model SR9000; Fig. 9) uses information on wind direction and speed (R.M. Young Model 12005; Fig. 8) and ozone concentration (Thermo Environmental Instruments, Model 49C; Fig. 7) at the middle point of the ring to control the gas release. This information is then transmitted to the central computer for real-time performance analysis and data archival.

Ozone is produced by passing oxygen gas through a high-voltage dielectric field in an ozone generator (PCI-Wedeco, Model GA40; Fig. 6). The release of ozone process gas is regulated through a computer-controlled linear flow valve (Teledyne Hastings, Model HCF-302; Fig. 5). The ozone gas, which is produced at low pressure and low volumes, must be diluted and pressurized with a carrier gas in order to work with the high-pressure fumigation system. With a bypass venturi injector (Mazzei Injectors, Model 384-X; Fig. 4), a 50% pressure drop across the venturi forces ozone to be mixed into the air stream, while the bypass assembly maintains pressure on the downstream side and controls flow. A maximum mixture of 0.4 $m^3 h^{-1}$ ozone is diluted with 68 $m^3 h^{-1}$ compressed air before delivery to the treatment plot.

Gasses are released into the plant canopy by an octagon of ½-inch ABS pipes at canopy height that encircles the 20-meter-diameter plot (Fig. 3). These pipes have laser-drilled air jets at a spacing of 15 mm on the edge facing outside the ring. When gasses are released through the air jets at high pressure (2.41 bar), there is a turbulent mixing of the released gas with the surrounding air, creating a diluting effect before the gas enters the ring. Average wind direction over a 1-minute interval controls the opening of three sides of the octagon that are most directly upwind from the ring. The outer two sides release approximately 1/3 less ozone to account for their angle to the wind direction.

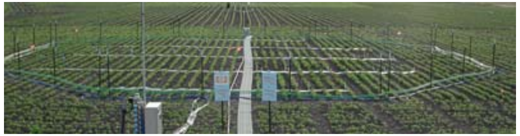

Figure 3.

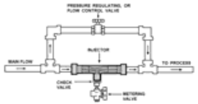

Figure 4. Venturi injector.

Figure 7. Ozone analyzer.

Figure 8. Wind measurement.

Figure 5. Linear flow controller.

Figure 9. Control computer.

Figure 6. Ozone generator.

RESULTS AND DISCUSSION

This ozone fumigation system is the first system to allow large-scale studies of ozone damage to an agronomic crop while avoiding the uncertainties imposed by the enclosures required by past ozone fumigation methods. The information collected from the various varieties grown within the treatment area will allow researchers to better understand ozone damage to soybeans and better prepare for future environments.

The current CO_2 FACE system at SoyFACE, based on the Miglietta design (Miglietta et al 2001), was modified to fumigate soybean with ozone. A bypass venturi injector was designed to blend low-pressure ozone with high-pressure ambient air for fumigation of the crop. Additionally, components of the existing CO_2 system were modified or replaced to prevent degradation by corrosive ozone.

The ozone treatment was approximately 25.5% above the ambient ozone concentrations measured over the growing season. A control target concentration inside the rings was set at 50% above the measured level and adjusted on a 1-minute interval. Average ozone concentrations were within 10% of the target concentration 82% of the time (1-minute-averaged readings), while 94% of these readings were within 20% (Fig. 11). In comparison, the CO_2 fumigation system performed at 87% of 1-minute averages within 10% and 96% of readings within 20%. The lower performance numbers for ozone fumigation are due to longer response time in sample analysis and ozone output lag time.

Ozone fumigation should be discontinued during the daytime under certain conditions, including wet leaves and safety issues. 1) Wet leaves: Leaf-wetness sensors were used to shut down fumigation. 2) Safety: Since ozone is dangerous to people at high concentrations, the system was shut down to prevent pockets of high-concentration ozone from forming at the release points when wind speeds were low and variable. (<0.5 $m\ s^{-1}$) Given these shutdown conditions, the field received fumigation 49% of daytime operating hours, resulting in the 25.5% increase above ambient in the 2003 growing season.

While uniformity of CO_2 treatment may be readily assessed with an open-path infrared CO_2 analyzer, there is no equivalent instrument for instantaneous sampling of ozone. Uniformity could be assessed with a biological proxy. Ozone exposure causes stomatal closure, decreased transpiration, and, therefore, warmer leaves in sunlight. A thermal image of the soybean canopy within the treatment ring shows an even warming (1–2ºC) relative to the crop outside of the ring. This study shows that the FACE method of Miglietta et al. (2001) can be successfully adapted to also simulate rising tropospheric ozone. The system has the advantage over earlier FACE systems of lower energy requirements to force air into the ring, and much lighter release pipes (cf. Lewin et al. 1999: McLeod & Long, 1999), which in turn require a less bulky support structure. In an arable crop setting, this has the important advantage of far more rapid assembly after sowing but before emergence, and similar removal at the end of the growing season.

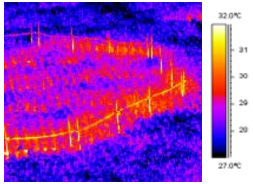

Figure 10. Uniformity of the ozone treatment over the treatment area as indicated by early senescence.

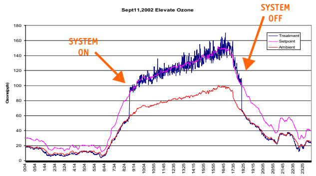

Figure 11.

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REFERENCES CITED

Lewin K.F., Hendrey G.R. & Kolber Z. (1992) Brookhaven National Laboratory Free-Air Carbon-Dioxide Enrichment Facility. *Critical Reviews in Plant Sciences*, **11**, 135-141.

McLeod A. & Long S. (1999) Free-air Carbon Dioxide Enrichment (FACE) in Global Change Research: A Review. *Advances in Ecological Research*, **28**, 1-55.

Miglietta F., Peressotti A., Vaccari F.P., Zaldei A., deAngelis P. & Scarascia-Mugnozza G. (2001) Free-air CO_2 enrichment (FACE) of a poplar plantation: the POPFACE fumigation system. *New Phytologist*, **150**, 465-476.