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CO_2 Fumigation System for the Prediction of the State of Forests in the Future:

Free Air CO_2 Enrichment Experiment in Northern Japan

Atmospheric CO_2 concentration is about 350-400 parts per million by volume (ppmv) at present, but it is predicted to increase up to 540-970ppmv by the end of the 21st century. Will the carbon fixation capacity of trees and forests change in the future? What is the fate of our forests in a world with an increased atmospheric CO_2 concentration? The Free Air CO_2 Enrichment (FACE) experiment hopes to provide some answers to these questions.

After Japan's ratification of the Kyoto protocol for moderating the increase of CO_2 in the atmosphere, we have speculated on the role of forest ecosystems in CO_2 uptake. To be able to evaluate the carbon balance of the atmosphere in the future, we urgently need to understand how forests or trees respond to the predicted high CO_2 environment. Many studies have investigated forests under elevated CO_2 and temperature conditions, simulating the global greenhouse effect. In Sapporo, Japan, we have established a small-scale Free Air CO_2 Enrichment (FACE) experiment, using the Vaisala CARBOCAP® Carbon Dioxide Probe GMP343.

Beyond earlier CO_2 enrichment experiments

During the early stages of the experiments, a closed chamber or open-top chamber (OTC) was used to regulate the CO_2 concentration. Unfortunately, since the conditions inside these chambers were otherwise quite different from the natural environment (e.g. in terms of temperature, moisture, light, and wind speed), it was ambiguous to apply the results directly to natural conditions. This is why the FACE system was developed. The FACE structure and the control system for CO_2 concentration is shown in Figure 1. Wind direction is detected with an anemoscope. The CO_2 sensor positioned at the center of FACE

Figure 1: Structure of the FACE system

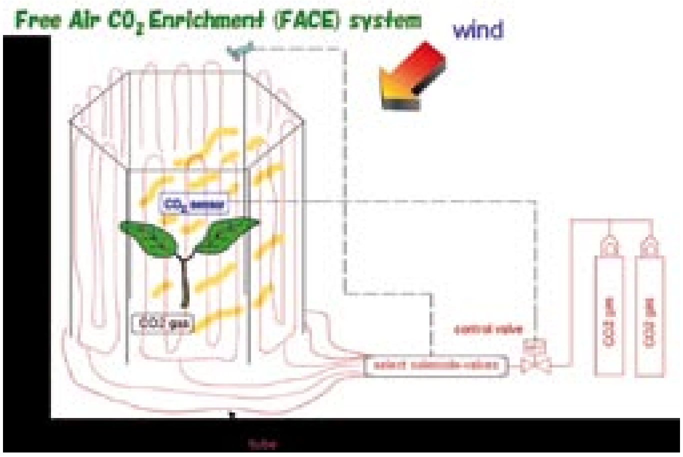

Figure 2: The Vaisala CARBOCAP® Carbon Dioxide Probe GMP343 inside the FACE.

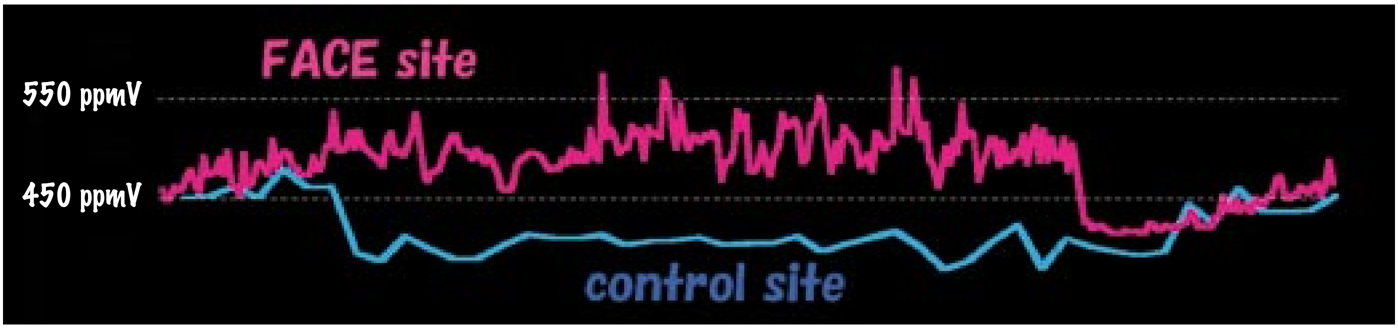

Figure 3: Daily variation of CO_2 concentration inside the FACE (August 25, 2004).

can regulate the rate of CO_2 gas released upwind from the hole in the tube and sustain the target CO_2 concentration.

The setting

The FACE system that we have constructed is located in the Sapporo Experimental Forest, Field Science Center for Northern Biosphere (FSC), Hokkaido University, in northern Japan (43˚06'N, 141˚20'E). It was designed and constructed by Mr. Tatsushiro Ueda, Technical Engineer at Hokkaido DALTON Co., under the supervision of Professor Takayoshi Koike from Hokkaido University. The system is based on the alpine FACE system of the Swiss Federal Institute of Technology (ETH, Zürich) and the University of Basel in Switzerland. The Hokkaido FACE system was completed in the spring of 2003. There are three five-meter high circular plots with a diameter of six meters each, that are maintained at elevated CO_2 levels. Three plots of six-meter diameter constitute a control group with ambient CO_2 levels. This is the first study for woody plants in Asia and it simulates the early stages of forest succession. Eleven kinds of deciduous tree saplings native to the cool-temperate region in Japan were used. These tree species are alder, two types of birch (white birch, Monarch birch), larch (early successional), basswood, kalopanax, Manchurian ash, elm (mid successional), maple, beech, and oak (late successional).

The target CO_2 concentration of the FACE system is aimed at 500 ppmv during daytime, which has been estimated to be the average level of atmospheric CO_2 in 2040. To control the CO_2 concentration, we introduced the Vaisala CARBOCAP® Carbon Dioxide Probe GMP343 (Figure 2). The accurate probe type of CO_2 sensor enables a well-regulated experiment. The CO_2 gas was supplied with a special tubing system used for irrigation in Australia. The tube has a knot at one-meter intervals for balanced CO_2 pressure, which helps in creating a uniform supply of CO_2 to the target space in FACE. The result of CO_2 concentration control is shown in Figure 3. The proportion of daytime (from 4:00 am to 7:00 pm) within the 500±50ppmv parameter was 95.02%, which is a very high accuracy.

The findings

We are now obtaining interesting results from our two-year FACE experiment. Under elevated CO_2 concentrations, the leaf stomata (the microscopic pores under the leaves, which open outside to give out oxygen and water vapor and take in CO_2) tended to close and the transpiration rate decreased in almost all tree species grown on both volcanic ash soil and brown forest soil. However, the photosynthetic rate of most species tended to increase. Consequently, the water use efficiency of leaves increased significantly. These results indicate that, under elevated CO_2 concentrations, the saplings would be able to keep up a high photosynthesis rate even in dry conditions.

In the second year of the experiment, photosynthetic downregulation (maximum photosynthetic rate at light and CO_2 saturation showed lower values in high CO_2 grown tree saplings than in ambient CO_2 grown ones) was found in white birch but not in alder. The amount of photosynthesis enzyme (Rubisco) in white birch at high CO_2 was lower with an extra-accumulation of starch in the chloroplasts than at ambient level CO_2. Contrary to white birch, no down-regulation was found in alder. Because of the symbiosis with actinomycete *Frankia* sp. - a large carbon sink and resource for nitrogen - alder could maintain a high photosynthetic rate. However, herbivore (plant eating animals, in this case mainly the leaf beetle; *Agelastica coerulea*) attacked its leaves, and most of the alder saplings died on volcanic ash soil which is poor in nutrients. Under infertile soil conditions, the photosynthetic capacity of alder would be accelerated by high CO_2 concentrations, accompanied by an increase in *Frankia* sp., which may supply nitrogen to alder as a host plant. Alder leaves with high nitrogen levels attract herbivores. These plant-insect interactions are also being studied in the FACE experiment.

With our experiment, we aim to understand the physiological and ecological traits of trees and forests in a CO_2 enriched world. Ultimately, we hope to accurately predict the carbon fixation capacity of forests in the future. ●

From left: T. Ueda, T. Koike, N. Eguchi, K. Karatsu, N. Morii, N. Ishida and T. Hida in front of a FACE plot.