EXPERIMENTAL CHAMBERS FOR AUTOMATIC FUMIGATION OF PLANTS WITH ELEVATED CO2 CONCENTRATION AND DROUGHT STRESS INDUCTION WITH THE USE OF RECIRCULATION

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ABSTRACT

Chambers designed for experimental station Domanínek (near Bystřice nad Pernštejnem), allow precise control of the CO_2 concentration in the atmosphere inside the chamber using a ventilation system with injection of gaseous CO_2 and feedback control based on the ongoing continuous measurement of CO_2 from individual chambers using an infrared analyzer. Ventilation of chamber is adjustable in various intensities by opening roof lamellas, and power control of the fan. This system allows maintaining a minimum temperature difference between outside and inside the chamber. The chambers are equipped with unique recirculation system which minimizes CO_2 consumption in conditions with minimal heating the air inside the chamber (cloudy, morning, evening). Control of chambers is performed automatically based on signals from the sensors and analyzers using specially developed software.

Key words: elevated CO_2 concentration, drought, chamber, recirculation, fumigation

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INTRODUCTION

Carbon dioxide (CO_2) is the second most abundant greenhouse gas after water vapour. The concentration of greenhouse gases was almost constant in the pre-industrial era. Due to anthropogenic activities such as burning fossil fuels and deforestation, the concentration of atmospheric CO_2 has risen dramatically from 280 to 380 ppm since the beginning of the industrial revolution (Denman et al. 2007). The annual rate of increase in the atmospheric CO_2 concentration is about 2 ppm (NOAA 2012). Without any effort to mitigate the atmospheric CO_2 concentration it may reach the level of more than 1 000 ppm by 2100 (Sokolov et al. 2009).

Over the years, a variety of techniques has been applied to study plant responses to elevated atmospheric CO_2. Early studies on the effects of elevated CO_2 were typically done under controlled conditions in closed chambers or greenhouses. A shortcoming of these difficult methods is that they create an artificial environment compared to natural ecosystem conditions. Attempts to bring experimental set-ups in a more natural context have yielded more elaborate techniques that tend to allow, to varying degrees, for an exchange with the natural environment. These include open top chambers (OTC - e.g., Vanaja et al. 2006) and free air CO_2 enrichment systems (FACE - e.g., Long et al. 2004).

In FACE systems, CO_2 is transported by a ring-shaped pipe surrounding the plot and is distributed by vertically oriented pipes. The dosage of the carbon dioxide depends on the actual CO_2 concentration inside the plot and climatic factors such as wind direction and speed. The valves of the vertical pipes can be closed and opened to adjust for changes in wind direction. To minimize experimental costs, CO_2-enriched air can thus be released only upwind (e.g., Hendrey et al. 1999). The main advantage of the FACE system is that the construction of FACE does not negatively affect the plot's microenvironment such as wind direction and speed, rain fall, snow fall, radiation, or the influence of insects. This enables the researcher to investigate the effects of elevated atmospheric CO_2 on ecosystems under natural conditions (Machacova 2010). Another advantage is that such system can be used to enrich the atmospheric CO_2 concentration in large trees. One of the greatest disadvantages of FACE experiments is the very high cost arising from the high consumption of CO_2 during fumigation.

In contrast to FACE, OTC systems have lower costs per experiment due to a significantly lower consumption of carbon dioxide, because air exchange is reduced by the closed side walls. However, within the OTCs the microclimatic conditions (mainly wind speed) are affected by the enclosure.

In the newly built experimental facility in Domanínek (near Bystřice nad Pernštejnem) we tried to combine this main advantage of OTC, saving costs, with another possibilities raising from enclosed environment. This is particularly the ability to manipulate rainfall and induce drought stress by closing rotating roof lamellas. Another advantage of the enclosed environment of OTC can be the possibility to manipulate the incident radiation. In our case, the use of acrylic materials with different transmission of UV radiation was used to evaluate the effect of the UV exclusion on plant growth and physiology.

MATERIAL AND METHODS

Experimental facility for evaluating the impact of global change on plants was built at the turn of 2012-2013 in cooperation with companies Konel s.r.o. (Zlín, CZ) and SWS Tauchman (Jilemnice, CZ). This facility is used to simulate future climate conditions, especially the effects of elevated CO_2 concentration, drought stress, the influence of UV radiation and increased temperatures. The basic part of the experimental station consists of 24 chambers of hexagonal ground plan with side length 2 meters and diameter of the circumscribed circle 4 meters. The basic height of chamber is 2 meters and above this construction is build the roof with rotating lamellas that allow controlling chamber ventilation and precipitation. Other key component of the station is the control unit with specially developed software and set of analysers and sensors necessary for automatic regulation of microclimatic conditions inside the chambers. These are particularly the infrared CO_2 analyzer Li 840 (Licor, USA), sensors for detection of position of roof lamellas and ventilation flaps and a set of sensors for measurement of microclimatic conditions such as air temperature and humidity, soil temperature and moisture, photosynthetic active radiation (PAR), UV-A and UV-B radiation, global radiation, rainfall and wind speed. The last major element of the facility is the tank for cca 10 tons of liquid CO_2 and evaporating station for CO_2 gasification. This also includes underground pipelines for the transport of gaseous CO_2 to the individual chambers. Gaseous CO_2 is injected into the fan, where it is mixed with air, which is then blown into the chamber bottom air channel with holes, which is located all around of the chamber. The air serves not only to increase the CO_2 concentration, but also to compensate the temperature of the surrounding environment. Automatically controlled solenoid valve is used for the injection that opens when the concentration of CO_2 in the chamber falls below desired value.

Sampling of air is carried out from fumigated chambers through tubes located in the center of the chamber about 1.5 meters above the ground. Air is drawn through a powerful pump from each chamber by switching the solenoid valves. The measured values can be averaged, and the fumigation performed in all the chambers equally, or it can be controlled for each chamber separately. The disadvantage of the second system is a considerable time lag between measurement cycles in one chamber.

The system allows ventilation to operate in two basic modes. At first mode the air is sucked out from outside and is blown into the bottom ventilation channel. The heated air then leaves the chamber by roof. Roof lamellas are open. The second system is used for small differences in temperature inside and outside the chamber, which is typical for morning and evening hours. This is actually the recirculation of air in which the air is sucked out from the upper air channel and re-blown by bottom channel (Fig. 1). Switching is done via rotary valves driven by a servomotor. In this case roof lamellas are closed.

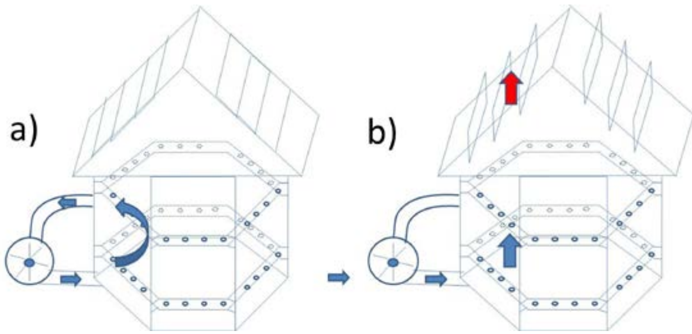

Fig. 1 Scheme of two modes of chamber ventilation:

a) The recirculation - air is sucked inside the chamber from the upper channel and is blown back by the bottom channel. The roof lamellas are in the closed position
b) Direct ventilation - air is sucked outside the chamber and blown into chamber by the bottom air channel. The heated air leaves the chamber through roof, and the lamellas are in the open position

The fan speed and thus its power can be adjusted by frequency converter. The system allows setting three steps of the fan power, while the first is used for recirculation and the other two for direct ventilation. In each step can be the power manually set. Switching the recirculation mode and the fan power is performed on the basis of the air temperature difference between the chamber and the outside environment.

Roof lamellas are automatically controlled by servomotor and have three basic positions. The first is open for direct ventilation, and the other two are closed for recirculation. Of these, one position is closed with the transmission of precipitation (wet) and the other is closed to avoid the precipitation transmission (dry).

In this study, we optimized the protocol of CO_2 concentration measurement and following fumigation, so that the concentration showed the lowest possible fluctuations.

Furthermore, the ventilation protocol was optimized, in order to meet the minimum difference between the outside temperature and temperature inside the chamber.

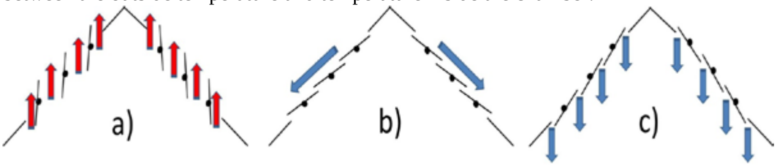

Fig. 2 Three basic positions of roof lamellas :

a) open (cooling) - the roof is open for ventilation of chamber and the fan runs on full power;

b) closed [dry] – the roof is not transmitting rainfall , fan runs on minimum power and the air is recirculating;

c) closed [wet] – rainfall pass through the roof, fan runs on minimum power and the air is recirculating

RESULT AND DISCUSSION

a) Optimizing the measurement and control of CO_2 concentration

Measurement of CO_2 concentration takes place sequentially in each chamber, wherein the air is sucked from chamber by a powerful pump and driven into CO_2 analyzer. Given that the distances from the chamber to the analyzer are of different lengths, it was necessary to optimize the time that is needed to clean air from the tubing. Based on the volume calculation of longest tubing and pump output the minimum time needed to transport a new air sample from the most distant chamber was determined 10 s. To ensure the certainty that there is no mixing of samples, we chosen the time between the start of pumping and start of measurement with infrared CO_2 analyzer 12 s. The actual measurement of CO_2 concentration shows on the stable average already when the time of measurement delay is in the range of 5-10 s. Therefore the length of measurement was chosen 8 s. This means that the measurement of CO_2 concentration in one chamber takes place for 20 seconds and the cycle of measurements in 12 chambers including outside concentration takes more than four minutes. Therefore, the fumigation can´t be controlled on the basis of the whole measurement cycle, and the procedure using on a floating average of last 3 measurements was chosen. This system allowed reducing the fluctuations in the CO_2 concentration within the chambers; however, this is still too high. Therefore, we propose a new system using two CO_2 analyzers and three pumps. One powerful pump sucks the air permanently from all chambers. Using the switching valve the air is then fed to one of two pumps with low power which then dose air sample to the CO_2 analyzer. The entire measurement cycle should thus be reduced to a period of less than a minute. In this system should be then possible to control the concentration of each chamber, because the minute delay of injection proves to be sufficient. It will be verified even in very hot days when ventilation is running at full capacity.

b) Optimizing the temperature control and ventilation of chambers

The aim of optimizing the protocol of chamber ventilation was to limit the rise in temperature within the chamber compared with the ambient environment and at the same time to eliminate CO_2 losses to necessary minimum. Empirically we set up three degrees of temperature differences between inside and outside the chamber, and this differences were 0.5 °C as the first step, and 1 °C and 1.5 °C as the second and third step, respectively. At the first step is the recirculation switched on and the fan runs at minimum power required for acceleration (12 %). Based on testing during hot days the fan power was set to 50 % at first step and to 75 % at second step, which are shown to be sufficient to reduce the temperature within a few minutes.

CONCLUSIONS

It turned out that the weakest part of the whole system is the measurement of CO_2 concentration which relatively long time does not allow controlling the fumigation individually in each chamber. The new measurement system which is currently installed based on two analyzers and three pumps should eliminate this weakness.

REFERENCES

DENMAN K. L., BRASSEUR G., CHIDTHAISONG A., CIAIS P., COX P. M., DICKINSON R. E., HAUGLUSTAINE D., HEINZE C., HOLLAND E., JACOB D., LOHMANN U., RAMACHANDRAN S., DA SILVA DIAS P. L., WOFSY S. C., ZHANG X., 2007: *Couplings between changes in the climate system and biogeochemistry.* "Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change" (Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL eds). Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 511-539.

HENDREY G. R., ELLSWORTH D. S., LEWIN K. F., NAGY J., 1999*:* A free-air enrichment system for exposing tall forest vegetation to elevated atmospheric CO_2. *Global Change Biology,* 5: 293-306. ISSN 1354-1013, Online ISSN 1365-2486.

LONG S. P., AINSWORTH E. A., ROGERS A., ORT D. R., 2004*:* Rising atmospheric carbon dioxide: Plants face the future. *Annual Review of Plant Biology,* 55, 55: 591-628. ISSN 1040-2519.

MACHACOVA K., 2010: Open top chamber and free air CO2 enrichment - approaches to investigate tree responses to elevated CO2. *iForest - Biogeosciences and Forestry* 3, 1: 102-105. ISSN 1971-7458.

NOAA (National and Oceanic Administration), 2012: *Recent global CO_2*. Available online: http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html.

SOKOLOV A. P., STONE P. H., FOREST C. E., PRINN R., SAROFIM M. C., WEBSTER M., PALTSEV S., SCHLOSSER C. A., KICKLIGHTER D., DUTKIEWICZ S., REILLY J., WANG C., FELZER B., MELILLO J. M., JACOBY H. D., 2009: Probabilistic forecast for twenty-first-century climate based on uncertainties in emissions (without policy) and climate parameters. *Journal of Climate,* 22, 19: 5175-5204. ISSN 0894-8755.

VANAJA M, MAHESWARI M, RATNAKUMAR P, RAMAKRISHNA Y. S., 2006: Monitoring and controlling of CO_2 concentrations in open top chambers for better understanding of plants response to elevated CO_2 levels. *Indian Journal of Radio and Space Physics* 35: 193-197. ISSN 0367-8393.