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A new canopy photosynthesis and transpiration measurement system (CAPTS) for canopy gas exchange research

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ABSTRACT

Accurate measurement of canopy gas exchange rates is crucial for studying canopy photosynthetic resource use efficiencies. We designed, created, and evaluated a new canopy photosynthesis and transpiration measurement system (CAPTS). The CAPTS included: (1) modular chamber sides, (2) sensors for temperature, CO_2, air pressure and humidity that were integrated on a removable chamber cover, and (3) a user-friendly console for control of automatic opening and closing of the chamber cover for data recording, storage and analysis. The CAPTS can accurately measure canopy photosynthetic CO_2 uptake rate, which was demonstrated with both rice and tobacco. The CAPTS provides a basic ability to measure rates of photosynthesis, respiration, and transpiration of plot-size canopies and other components of agro-ecosystems.

1. Introduction

Canopy photosynthetic CO_2 uptake rates, i.e., the integrated photosynthetic rates of all leaves inside of a canopy, are positively correlated to crop yields (Wells et al., 1982; Zelitch, 1982). Therefore, identifying methods to improve canopy photosynthetic CO_2 uptake rate is important for breeding high-yielding crops. However, to date there is no easy-to-use effective and quick tool for screening and measuring canopy photosynthesis, particularly in plot-size canopies. Historically, canopy photosynthetic CO_2 uptake rate (A_c) was measured by micrometeorological approaches, such as the Bowen ratio/energy balance method (Held et al., 1990), the eddy correlation method (McMillen, 1988), and canopy chamber approaches (Bugbee, 1992). The canopy chamber approach includes both open chamber systems (Long et al., 1996; Dragoni et al., 2005; Graydon et al., 2006; Burkart et al., 2007; Muller et al., 2009) and closed chamber systems (Reicosky, 1990; Wagner and Reicosky, 1992; Steduto et al., 2002; Pérez-Priego et al., 2010).

The Bowen ratio/energy balance (BREB) method measures the gradient of humidity and temperature for use in calculating the Bowen ratio, which is the ratio of light energy dissipated as sensible heat to the light energy dissipated as latent heat. The Bowen ratio is then used to calculate the flux of sensible and latent heat from a canopy with an energy balance equation (Cellier and Olioso, 1993). The BREB method is usually used to measure water vapor flux, but it can also be used to measure CO_2 fluxes assuming that the eddy transfer coefficients for sensible heat, water vapor and CO_2 are equal (Held et al., 1990; Johnson et al., 2003). The eddy correlation method measures the vertical wind velocity and CO_2 or H_2O concentration simultaneously, which are used to estimate the vertical fluxes of CO_2 or H_2O (McMillen, 1988). The advantage of these two micrometeorological methods is that they do not disturb plant canopy structure and canopy microclimate; however, these methods cannot be used for plot-size canopies.

For a plot-size measurement, canopy chambers are a suitable option (Dugas et al., 1991, 1997; Dugas, 1993; Angell et al., 2001; Johnson et al., 2003). Canopy chambers have been used for studying the influence of plant age on photosynthesis (Peng and Krieg, 1991), for tracing ^{13}C in soil respiration (Barthel et al., 2010), and for studying the effects of elevated CO_2 concentration on plant

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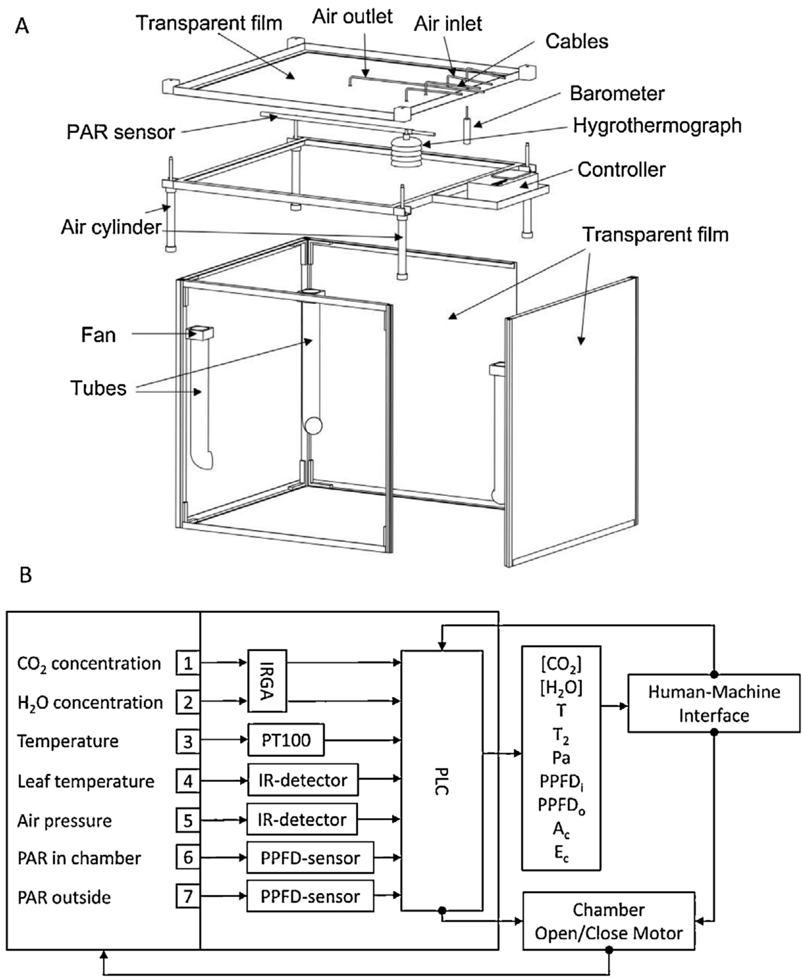

Fig. 1. Design of the CAPTS. (A) The CAPTS included the following components: four sides that can be assembled to form a chamber, four fans that were fixed at different positions inside the CAPTS, one top cover that integrated sensors, a programmable logic controller that can collect and analyze signals from sensors, and a touchscreen monitor. (B) The sensors mounted on the top cover of the CAPTS.

photosynthesis and transpiration (Hileman et al., 1994). The open canopy chamber system (Long et al., 1996; Dragoni et al., 2005; Graydon et al., 2006; Burkart et al., 2007; Muller et al., 2009) measures gas concentrations at a gas inlet and outlet of a chamber as well as the gas flux rate through a canopy chamber (Long et al., 1996). A canopy chamber can continuously measure gas exchange rates inside a chamber with precise control of environmental parameters (Muller et al., 2009). The closed canopy chamber system measures gas exchange rate by measuring the changes in concentrations of CO_2 and water vapor inside the chamber (Reicosky, 1990; Wagner and Reicosky, 1992). To continuously measure canopy photosynthesis, an automated closed-system canopy chamber has also been developed (Steduto et al., 2002) and been used for studies of small canopies, such as weeds.

With recent emerging interest in improving canopy photosynthesis for improved crop yields, the development of new canopy photosynthesis and transpiration measurement systems that can accurately measure canopy gas exchange in a plot-size canopy is needed. This report describes the design, implementation, and evaluation of a new canopy photosynthesis and transpiration measurement system (CAPTS). This CAPTS had a number of novel features which enables it to be used as a basic tool to study photosynthesis, respiration, and transpiration of plot-size canopies or other components of agro-ecosystems.

2. CAPTS design

2.1. Components of the CAPTS

The canopy photosynthesis and transpiration measurement system (CAPTS) consisted of a number of parts that can be easily dissembled and re-assembled using custom-designed connection units (Fig. 1). The CAPTS was one meter long, one meter wide, and 1 to 1.5 m high. Rubber material was used between the chamber cover and chamber sides to prevent gas leakage. A polycarbonate plate, which has a light transmittance of ~0.9, was used to build the chamber sides and the chamber cover. The frame of the CAPTS was made of aluminum (Fig. 1B). All controllers and sensors (discussed in detail below) were fixed on the cover of the CAPTS. Air at four positions inside the CAPTS was sampled, pooled, and analyzed by an infrared CO_2 gas analyzer. Four fans were installed inside the CAPTS to ensure sufficient gas mixing. The power of the fans were selected to ensure sufficient air mixing.

2.2. Sensors

Two photosynthetic active radiation (PAR) sensors (LI-190 and LI-191, Licor, USA) were fixed on the cover, with one (LI-190) fixed on the top side of the cover to measure total incident PAR and the other (LI-191) fixed below the cover to measure PAR transmitted