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Improving the Quality and Reliability of Gas Exchange Measurements

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There are three common types of portable gas exchange systems: closed system, semi-closed system and open system . Some systems can be used as an open system, semi-closed or closed system by re-configuring the gas circuit. In a closed system, there is no air flow into or out of the leaf chamber once the leaf chamber is closed. In such a system, gas exchange rates (photosynthesis and transpiration) of the enclosed foliage are calculated based on the rate of change in CO2 and H2O concentration over time. A closed system cannot produce a real steady state measurement because the concentrations of both water and CO2 change continuously in one direction. Additionally temperature control in a closed system is more difficult because heat will accumulate. A semi-closed is basically a closed system with CO2 injection to compensate for the CO2 drawdown by photosynthesis. In an open gas exchange system, the air in the leaf chamber is replaced continuously and the rate of replacement is determined by the user-set air flow rate. In such as system, the rates of photosynthesis (or respiration) and transpiration are calculated based on the air flow rate and concentrations differences between input and output air. All modern open gas exchange systems have the capacity to control CO2 and humidity in the leaf chamber (as detailed in the following two sections), but not all systems can regulate temperature and light levels. It should be noted that the boundary layer resistance in leaf chambers generally is much lower than the values in a natural environment due to the effect of the high speed mixing fan in the leaf chamber.

There are two measurements in an open gas exchange system: the analysis CO2 and reference CO2 concentration. The reference CO2 concentration is the CO2 concentration in the input air into the leaf chamber while the analysis CO2 is the CO2 concentration in the air coming out of the leaf chamber. Nearly all modern gas exchange systems control CO2 concentrations in the leaf chamber by stripping out all of the CO2 from the intake air and then add pure CO2 from a pressurized canister at a modulated rate as determined by the rate of air flow and the user-set target CO2 concentration. It is important to understand that the reference CO2 concentration is not what the foliage is exposed to. As the input air enters the leaf chamber, it is immediately mixed with the air in the leaf chamber by a high speed mixing fan. Therefore, the CO2 concentration at the leaf surface is approximately the same as the analysis CO2. Thus the analysis CO2 should be used as the Ca for calculating the internal to ambient CO2 ratio (Ci/Ca).

Furthermore, since the rate of photosynthesis tends to differ between samples, particularly between different treatments, and for conifers the amount of foliage enclosed in the leaf chamber also varies between samples, the analysis CO2 can be different between different samples measured at the same reference CO2 concentration. The difference (drawdown) between the reference CO2 and analysisCO2 concentration is also influenced by the rate of air flow through the leaf chamber: the greater the flow rate is, the smaller the difference will be. Because the measured rate of photosynthesis is a function of the CO2 concentration at which the measurement is taken [3], different samples and different treatments should be measured at the same or at least similar analysis CO2 concentrations.

Gas exchange parameters (e.g., photosynthesis, transpiration and stomatal conductance) are commonly expressed on a leaf area basis. There are three different measurements of leaf area: total surface area, hemi-surface area (50% of the total surface area) and projected area. The selection of a leaf area measurement affects the interpretation of the measurement and the comparability among different studies and different species. For flat leaves, the total surface area includes the area of both sides. For the same measurement, semi-surface area based rates will be twice as high as those that are expressed on a total surface area basis. When selecting the leaf area measurement to use, one should consider the distribution of stomata and the light source for the measurement. For flat leaves with stomata distributed only on one side of the leaf, projected or semi-surface leaf area should be used. On the other hand, if stomata are distributed on both sides of the leaf and the light levels are similar on the two sides, total surface area can be used. If light is supplied from a light unit mounted on the leaf chamber, projected leaf area is recommended because the light normally comes from one direction and the quantum flux density is measured on a projected area basis (i.e., per unit of area perpendicular to the direction of the light). The use of projected leaf area is particularly important in the measurement of photosynthetic light response curves, especially for coniferous species.