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High-tech leaf replica to measure plant-relevant microclimate

Stan Schymanski (1), Cesar Pascual Garcia (1), Oliver O'Nagy (1), and Phillip Dale (2)

(1) Luxembourg Institute of Science and Technology, Belvaux, Luxembourg, (2) University of Luxembourg, Belvaux, Luxembourg

Plant leaves absorb shortwave radiation and exchange longwave radiation, heat, water vapour and CO_2 with the atmosphere. Both CO_2 uptake and water loss happen through micrometric stomata that open and close to avoid excessive water loss or overheating.

The amount of CO_2 uptake per amount of water lost (water use efficiency, WUE) depends strongly on microclimatic conditions within the canopy, including absorbed irradiance, wind speed, air temperature and humidity. Accurate observation of the conditions experienced by a particular leaf is difficult as they depend on the precise position and angle of the leaf in the canopy. Miniaturisation and integration of sensors can represent a step forward to obtain more relevant local measurements.

Here we present the first steps to develop high-tech leaf replica capable of measuring the relevant microclimatic conditions experienced by a particular leaf within a canopy. All of the leaf energy balance components, except for shortwave absorption, depend strongly on the leaf temperature: the leaf emits black body radiation as a non-linear function of its surface temperature, it exchanges sensible heat with the air (by convection) in proportion to the temperature difference between its surfaces and the air, and latent heat flux (transpiration) scales with leaf temperature following the Clausius-Clapeyron relation. Therefore, accurate measurements of leaf temperature are pivotal to the determination of the leaf microclimate, including wind speed, irradiance and air humidity.

Leaf surface temperature is difficult to measure, as radiometric measurements are inherently inaccurate due to emissivity and reflectivity issues, while temperature sensors attached to a surface partly measure the temperature of the surrounding air. To measure the surface temperature of an artificial leaf, we integrated micofabricated thermocouples using laser optical lithography prototyping and metal evaporation. Because of their minimal heat capacity and optimised contact to the surface, their readings represent accurate surface temperature that determines convective and infrared heat exchange. Additional miniaturized thermocouples positioned outside of the leaf boundary layer on both sides of the artificial leaves are used to measure air temperature and the difference between surface and air temperature can be used to determine the convective heat transfer coefficient in the absence of latent heat flux if the amount of absorbed radiative energy is known. Steady-state absorbed radiative energy can be obtained by measuring the heat flux across the artificial leaf, using different coatings to distinguish different wavelength bands. Air humidity is calculated by the temperature difference between a wet and a dry part of the artificial leaf, similar to a wet bulb thermometer.

In this poster, we will present the theory and the progress towards a first prototype, highlighting various promises and pitfalls.