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Hyperspectral and thermal sensing of stomatal conductance and photosynthesis under water stress for a C3 (soybean) and a C4 (maize) crop

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Currently, the agricultural sector accounts for more than 90% of the water footprint of humanity. Reducing crop water footprints is urgent, especially considering that droughts are becoming more frequent. Unmanned Aerial Systems (UAS) carrying hyperspectral and thermal sensors can help by quantifying crop water use and photosynthesis at the farm scale. Remote sensing models could benefit from better parameterizations of plant responses to water stress. Current parameterizations group plants that might have different functional traits. In addition, they rely on meteorological variables and vegetation indices like the Normalized Difference Vegetation Index (NDVI). As a response to stress, crops modify leaf transpiration, photosynthesis and conductance, and the associated energy balance in the shortwave and longwave ranges. Therefore, UAS can help to better quantify water stress responses using ad-hoc dynamic parameterizations. This requires a careful identification of the spectral wavelengths which are most sensitive to changes in water stress.

In this study we assess the sensitivity of different indices and spectral regions to changes in leaf conductance, photosynthesis and transpiration due to water stress in soybean and maize, with different photosynthetic paths (C3 and C4) and differing strategies for stomatal regulation (anisohydric/isohydric).

The experiment was conducted in a growth chamber at the phytotron Risø Environmental Risk Assessment Facility (RERAF), Technical University of Denmark (DTU). The crops were grown under typical meteorological conditions of Southern Europe (25^0C/50% RH daytime) with 3 water stress treatments: control (100% of field capacity, FC), medium (70% FC) and high-water stress (40% FC) with 6 replicates per treatment. Canopy reflectance and temperature were measured with a hyperspectral camera Cubert UHD 185 with 125 bands (450-950 nm) and a Flir-Tau2 thermal infrared camera, respectively. Canopy evapotranspiration was measured by gravimetry, and leaf stomatal conductance, transpiration and photosynthetic rates were measured with a Li-Cor-6400.

We found contrasting responses in water and carbon regulation between the two crops for similar water stress levels. Our results suggest that for soybean and maize under the same levels of water stress, soybean undertakes physiological adjustments, while maize responds with reductions in biochemical constituents, such as pigments or leaf water content. In general, leaf conductance, transpiration and photosynthesis were lower and presented larger responses to water stress for soybean (C3) than for maize (C4). In soybean, the air–leaf temperature difference (ΔT) was the variable most sensitive to changes in conductance and transpiration, while this was not the case in maize. This is consistent with larger changes in conductance observed in soybean that will reduce transpiration cooling. The Photochemical Reflectance Index (PRI) and ΔT were also sensitive to photosynthesis for soybean. For maize, the Water Index (WI) was sensitive to conductance and transpiration, suggesting reductions in leaf water content but not in soybean. Pigment content indices such as the Optimized Soil-Adjusted Vegetation Index (OSAVI) as well as NDVI were responsive to transpiration and conductance for maize. These results highlight the benefit of using different spectral indices and regions to track plant water status and accounting for different functional traits when modeling evapotranspiration or photosynthesis.