Enhanced Plant Water Status Measurement using THz Time-Domain Spectroscopy

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INTRODUCTION: Plant water status can be used as a reliable indicator for irrigation schedule to improve water use in agriculture. For this purpose non-destructive monitoring of leaf/plant water content has gained major interest. Recently, several studies demonstrated the potential of THz Time-Domain Spectroscopy (TDS) for non-destructive leaf-water measurements [1-2]. In these studies, leaf modeling used for data analysis considered a single heterogeneous layer made up of water, air, and dried tissue. Most of these studies focused on the plant response to severe drought. In this work, we focus on mild water stress for physiological leaf water contents which range between full turgor and turgor loss point. In addition, we take a closer look at the physical modeling of the leaf by using a more realistic multilayers approach.

RESULTS: Experiments were performed on Ivy leaves (*Hedera helix*). Gravimetric and THz measurements were carried out simultaneously on a single leaf disc dehydrating in the ambient atmosphere. Before measurements, leaf discs were enclosed in closed petri dishes with humidified filter paper in darkness at 5 °C for 12-24 h to allow full rehydration of leaf tissue. The THz measurements were carried out using a fiber-coupled THz TDS system in transmission mode employing a collimated beam. The THz and gravimetric measurements were done at the sampling rate of 15 Hz and 5 Hz, respectively. The RWC, that expresses the water content at a given time as relative to its fully turgid state, was calculated using equation 1 as: $RWC_t^{grav.}(\%) = \frac{W_t - W_{dry}}{W_{sat} - W_{dry}}.100 \, (1)$

where W_t, is weight measured at given time and W_{dry} and W_{sat} are weights in dried and water saturated states respectively. The initial disc weight (W_{t0}) is used as W_{sat} which corresponds to full turgor. To determine W_{dry}, disc was oven dried at 75 °C for 24 h after measurements.

Fig. 1 (a) represents the transmission at a frequency of 200 GHz as a function of dehydration time. The results showed a clear increase in transmission as the leaves loosed water, which demonstrates the high sensitivity of THz approach even at high water content. In Fig.1 (b), we compare the RWC derived from the gravimetric and THz measurements. The leaf model used in this example is a simple heterogeneous layer made up of water, air, and dried leaf tissue. We note a significant deviation between the two methods, the relative error is up to 5%, which prevents a reliable evaluation of leaf water content from THz measurement.

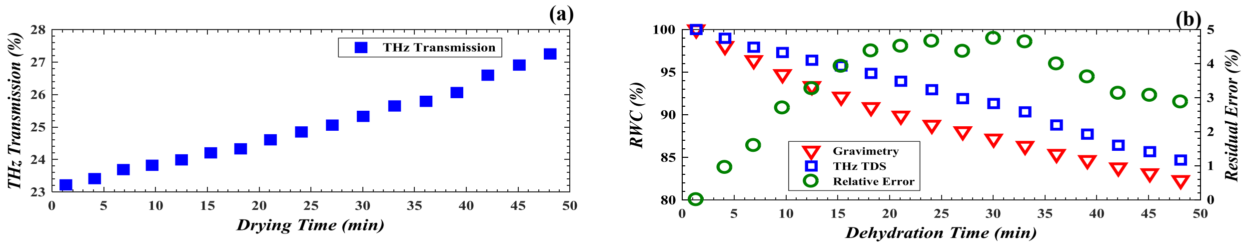

Fig. 1. *a) THz transmission at 200 GHz as a function of dehydration time. b) Comparison of gravimetric (triangles) and THz (squares) measurements of the RCW of ivy leaves and their corresponding absolute relative error (circle).*

Typical leaf anatomy [3] shows that distinct tissue layers compose the leaf and makes it a complex medium. We approximated the leaf by a multilayer model composed of distinct layers mimicking the different tissues. Based on typical volume density of the layers in terms of water, air, and dried tissue, we synthesized transmitted signals through a leaf. A dedicated root finding algorithm applied to the same virtual leaf but considering one layer model leaded to residual errors in RWC estimation similar to those using experimental data. In order to improve the water content estimate especially at high RWC a refined model of the leaf was therefore mandatory. More statistical analysis of the root finding algorithm for the inverse problem extraction process with refined models is currently ongoing. Future work will include experimental validation.

SUMMARY: We re-evaluate estimation of leaf water content using THz Time-Domain Spectroscopy. Using numerical simulations based on a realistic multilayer leaf model we show that the limitations of the one heterogeneous layer model and suggest new experimental strategy to overcome them.

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