A SMALL-SCALED EXPERIMENT TOWARDS THE HIGH-RESOLUTION ESTIMATION OF SOIL HEAT CAPACITY: A COUPLED HEAT PULSE AND DISTRIBUTED TEMPERATURE SENSING APPROACH

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Abstract: Soil heat capacity ($C_s$, J.m⁻³°C⁻¹) is essential to the maintenance of several energy and hydrological processes. In recent years, the monitoring of $C_s$ has been highlighted by the distributed temperature sensing (DTS) technology, which uses fiber optic cables (FOC) as sensors and allows data collection with high spatial and temporal sampling resolution. To quantify $C_s$, the dual-probe heat pulse (DPHP) method coupled with DTS measurements is used, constituting the DPHP-DTS approach. In this approach, a heat pulse is generated from a heating material (i.e., a heater), positioned parallel and a few millimeters away from the FOC. The thermal response of the surrounding soil to heating is used to estimate $C_s$ with well-established solutions to the general equation of heat transfer in porous media. In this study, we applied the DPHP-DTS approach on a small-scale laboratory experiment to estimate $C_s$ of a typical tropical soil, within different soil moisture contents ($\theta$, m³.m⁻³). As a heater, we used a metallic alloy composed of iron, chrome, and aluminum, while the temperature increase was measured by a FOC connected to a DTS. The DTS unit used was configured to collect data with spatial and temporal sampling resolutions of 25 cm and 20 s, respectively. From a total of ten $C_s$ - $\theta$ pairs obtained, we observed that the $C_s$ estimates with an analytical model increased as $\theta$ increased. Our results also indicated that the calculated $C_s$ values were very close to $C_s$ measurements obtained from field data. Therefore, our experimental findings point out the potentiality of the DPHP-DTS approach as a high-resolution tool for the monitoring of soil thermal properties.

Keywords: Soil thermal properties, heated fiber optics, unsaturated tropical soil, temperature as a tracer.

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INTRODUCTION
The soil heat capacity ($C_s$, J.m$^{-3}$.°C$^{-1}$) monitoring is fundamental to effective natural resources management, as it reflects the heat and water transfer across the land surface and subsurface. In this study, the DPHP-DTS approach was used to estimate $C_s$ of a typical tropical soil under different soil moisture conditions ($\theta$, m$^3$.m$^{-3}$) in a laboratory experiment.

MATERIALS AND METHODS
The soil used in this study is a sandy clay loam collected at the Foundation Test Site of the University of São Paulo. The small-scale experiment was built using a 200-mm-diameter, 1-meter-long PVC pipe. The longitudinal axis of the pipe was kept horizontal, and it received a total soil height of 130 mm. The heater, the FOC, and three soil moisture sensors were buried in the same horizontal soil profile, at 60 mm depth (Fig. 1a). As Shehata et al. (2020), we estimated $C_s$ with the Knight & Kluitenberg (2004) analytical model:

$$C_s \approx \frac{q't_0}{\pi r^2 \Delta T_m} \left(1 - \frac{\varepsilon^2}{24} - \frac{5}{128} \varepsilon^4 - \frac{7}{192} \varepsilon^5 \right)$$

Where $q'$ is the heating power (= 21.4 W.m$^{-1}$), $t_0$ is the heating duration (= 180 s), $r$ is the center-to-center distance between the heater and the FOC (= 9.58 mm), $\Delta T_m$ is the maximum temperature rise from the pre-pulse condition (°C), and $\varepsilon = t_0/t_m$, in which $t_m$ is the time from heat pulse start until $\Delta T_m$ is reached (s).

RESULTS AND DISCUSSION
$C_s$ values increased in function of $\theta$ (Fig. 1b) as water provides more heat storage potential to the soil (Sourbeer & Loheide II, 2015). Morais et al. (2021) estimated $C_s$ of the Foundation Test Site soil profile from field data and found that it ranged from 2.10 MJ.m$^{-3}$.°C$^{-1}$ ($\theta = 0.17$ m$^3$.m$^{-3}$) to 2.40 MJ.m$^{-3}$.°C$^{-1}$ ($\theta = 0.25$ m$^3$.m$^{-3}$). Our calculations indicated that, for $\theta = 0.18$ m$^3$.m$^{-3}$, the $C_s$ was 2.12 MJ.m$^{-3}$.°C$^{-1}$, and for $\theta = 0.25$ m$^3$.m$^{-3}$, $C_s$ was 2.41 MJ.m$^{-3}$.°C$^{-1}$. The similarity of the $C_s$ values between field estimates and our experimental results highlights the potential of the DPHP-DTS approach to quantify $C_s$ with high-resolution.
REFERENCES


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