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 (θ, m^3.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 - θ pairs obtained, we observed that the C_s estimates with an analytical model increased as θ 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 (θ, m^3.m^{-3}) in a laboratory experiment.

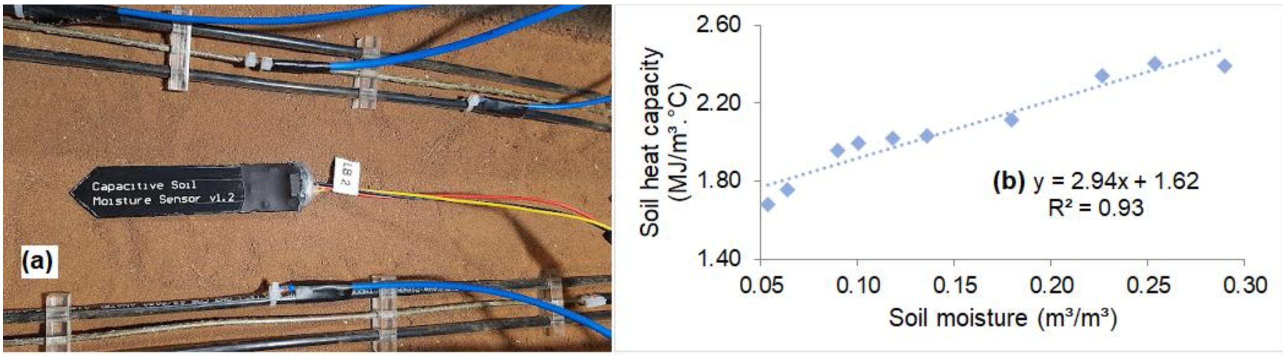
MATERIALS AND METHODS

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:

$$C_s \approx \frac{q' t_0}{e \pi r^2 \Delta T_m} \left(1 - \frac{1}{24}\varepsilon^2 - \frac{1}{24}\varepsilon^3 - \frac{5}{128}\varepsilon^4 - \frac{7}{192}\varepsilon^5\right) \quad (1)$$

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), ΔT_m is the maximum temperature rise from the pre-pulse condition (°C), and ε = t_0/t_m, in which t_m is the time from heat pulse start until ΔT_m is reached (s).

Figure 1 – (a) Detail of the small-scaled experiment and (b) C_s estimates as function of θ. Please note in (a) that the blue wires are thermocouples (not included in this study).



RESULTS AND DISCUSSION

C_s values increased in function of θ (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} (θ = 0.17 m^3.m^{-3}) to 2.40 MJ.m^{-3}.°C^{-1} (θ = 0.25 m^3.m^{-3}). Our calculations indicated that, for θ = 0.18 m^3.m^{-3}, the C_s was 2.12 MJ.m^{-3}.°C^{-1}, and for θ = 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.

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