Simultaneous measurement of soil matric potential and water content with dual probe heat pulse

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Soil matric potential (Ψ_m) and soil volumetric water content (θ) are important hydraulic properties which control liquid water transfer in vadose zone. Those properties also can be utilized for evaluating slope stability and for managing irrigation. There are several methods to measure Ψ_m and θ, e.g., tensiometer, time domain reflectometry, and capacitance sensor. Those sensors have been commercialized and widely used. However, there are no commercialized sensor which can measure both Ψ_m and θ simultaneously, and, thus, they have been measured independently by installing multiple sensors at the same location. In that case, there are several problems that sensors interact one another, each sensor has different sampling volume, and moreover, purchasing multiple sensors requires a large cost. Therefore, the objective of this study is to develop a sensor that can measure Ψ_m and θ simultaneously, and to evaluate its performance.

We developed a sensor measuring Ψ_m and θ simultaneously by improving the sensor design of a Ψ_m sensor made of porous media in conjunction with dual probe heat pulse (DPHP) technique developed by Kojima et al. (2017). DPHP is a method to simultaneously measure volumetric heat capacity (C) and thermal conductivity (λ) of soil. Kojima et al. (2017) applied DPHP to a porous medium made of Kaolinite and equilibrated with surrounded soil. They measured C and λ of the porous medium and converted them into Ψ_m by the preliminary obtained relationship. We extended the DPHP probe in the porous medium from 40 mm to 80 mm, and made them projecting into soil. By this change, the sensor can measure thermal property in two places, i.e., in porous media and in soil. Ψ_m is estimated from the thermal properties of porous media, and θ is estimated from C of soil.

An experiment to obtain relationships between thermal properties of porous media and Ψ_m, and to evaluate the accuracy of θ estimation by the developed sensor (hereafter, DPHP Ψ_m-θ sensor). A cylindrical container (46 cm diameter and 9 cm height) was filled with soil (Andisol) with a bulk density of 0.84 Mg cm^{-3}. Five DPHP Ψ_m-θ sensors, two 5TEs (METER Group, Inc.) which measure θ, two MPS-6s (METER Group, Inc.) which measure Ψ_m, and one tensiometer were inserted at 4.5 cm depth. The soil in the container was left in a constant temperature room (20°C) after it was saturated by tap water. The soil was naturally dried by evaporation for 30 days. The relationship between thermal properties of porous media measured with DPHP Ψ_m-θ sensor and Ψ_m measured with tensiometer and MPS-6 was evaluated. And the accuracy of θ estimation with DPHP Ψ_m-θ sensor was evaluated by comparing the estimated θ to that measured with 5TE.

The relationships between Ψ_m and C or λ of porous media could be expressed by a modified water characteristics curve model. Accuracies of Ψ_m estimation from C were 13%-18%, and those from λ were 13-15%. Thus, Ψ_m estimation from λ is more accurate than that from C. In addition, the measurable range of Ψ_m with λ was wider than that with C. While using λ to estimate Ψ_m had advantages in sensor performance, using C to estimate Ψ_m was more practical because the relationship between Ψ_m and C did not show significant inter-individual differences and temperature dependence. Each thermal property has advantages so that we can use both properties to accurately determine Ψ_m. The accuracy of θ estimation

with DPHP Ψ_m-θ sensor was 6% which is sufficiently high.

In this study, a DPHP based sensor measuring Ψ_m and θ simultaneously was developed. The developed sensor could estimate Ψ_m and θ accurately, thus, it can be a powerful tool for variety of studies in vadose zone.

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