High-Resolution Mapping of Surface Soil Moisture with Hyperspectral Line-Scan Imaging

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Introduction

- Time-lapse hyperspectral imaging provides an exciting new avenue for high-resolution mapping of Darcy-scale surface moisture redistribution processes with the potential for rapid estimation of soil hydraulic properties. In this pilot study we have employed a benchtop hyperspectral line scan imaging system to generate high resolution surface reflectance maps during moisture redistribution experiments. The obtained surface moisture information was employed to inversely determine the van Genuchten-Mualem soil hydraulic function parameters with HYDRUS-2D.

Materials and Methods

- A Resonon Pika NIR line scan camera with a spectral range from 900 to 1700 nm and a spectral resolution of 5.5 nm was employed to image water redistribution within an initially dry soil sample compacted into a square container.
- The water was applied at constant rate via a surface emitter tube fed by a computer controlled syringe pump (Fig. 1).

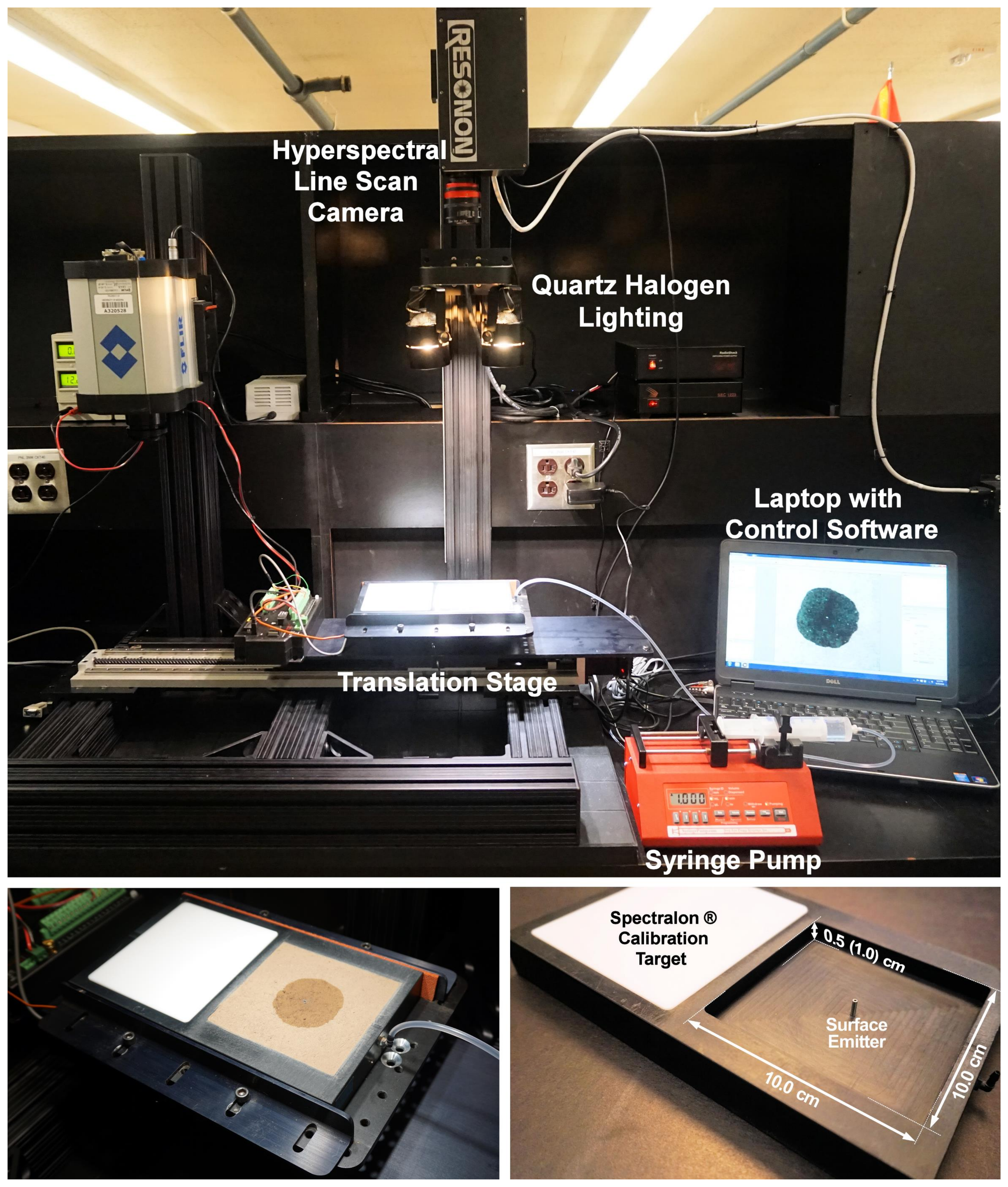

Figure 1: Experimental setup with close-up views of a sample container (during acquisition the sample moves relative to the steady camera).

- After scanning, the physically-based *Sadeghi et al. (2015)* model for near-surface soil moisture estimation from shortwave infrared reflectance was applied to generate time-lapse surface moisture distribution maps (Fig.4):

$$\theta/\theta_s = [(r - r_d)/(r_s - r_d)]$$

where θ is the actual water content, θ_s is saturated water content, r is the transformed reflectance $[1\text{-}R]^2/2R$ with R as the spectral reflectance at 1650 nm, r_d and r_s are the transformed reflectance of dry and saturated soil, respectively.

- The time-lapse surface moisture information was then used to parameterize the HYDRUS-2D numerical model to inversely determine the *van Genuchten (1980)* hydraulic function parameters α and n as well as the saturated hydraulic conductivity K_{sat}.

$$S_e = \frac{\theta-\theta_r}{\theta_s-\theta_r} = \left[\frac{1}{1+(\alpha h)^n}\right]^m \; ; \; \frac{K(S_e)}{K_{sat}} = S_e^{\frac{1}{2}}\left[1-\left(1-S_e^{\frac{1}{m}}\right)^m\right]^2$$

Materials and Methods - Continued

- The problem was setup as an axis symmetrical simulation in HYDRUS 2D/3D (*Šimůnek et al., 2016*) with boundary conditions depicted in Fig. 2. The moisture time series obtained from hyperspectral imaging for an observation node located 2.5 cm from the center was used in the objective function to inversely determine α, n, and K_{sat}.

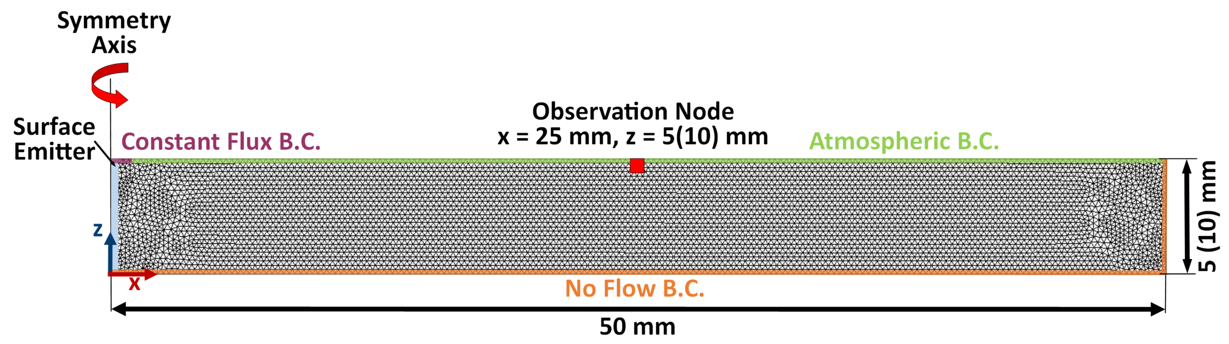

Figure 2: Simulation domain with applied boundary conditions.

- As a preliminary proof of concept, measurements and simulations were conducted for 3 Arizona source soils with vastly different textures (Tab. 1). In addition, different container depths and syringe pump discharge rates were tested. The sample surface was scanned every 30 seconds until the entire sample was saturated. The soil surface reflectance was referenced to a white Spectralon® calibration target.

Table 1: Physical properties of investigated soils.

Soil	Clay (%)	Sand (%)	OM (%)	BD (g.cm^{-3})	θ_r (cm^3 cm^{-3})	θ_s (cm^3 cm^{-3})
AZ 3	5.3	80.8	1.5	1.67	0.05	0.351
AZ 10	16.7	37.4	3.5	1.34	0.02	0.464
AZ 18	52.2	29.2	4.0	1.29	0.01	0.504

Preliminary Results

- Figure 3 depicts a series of measured reflectance spectra for image pixels with an Euclidian distance of about 2.5 cm from the center. With increasing water content the reflectance decreases for all wavelengths. The decrease is more pronounced in the SWIR electromagnetic frequency range (> 1300 nm), especially for the major water absorption band at around 1400 nm.

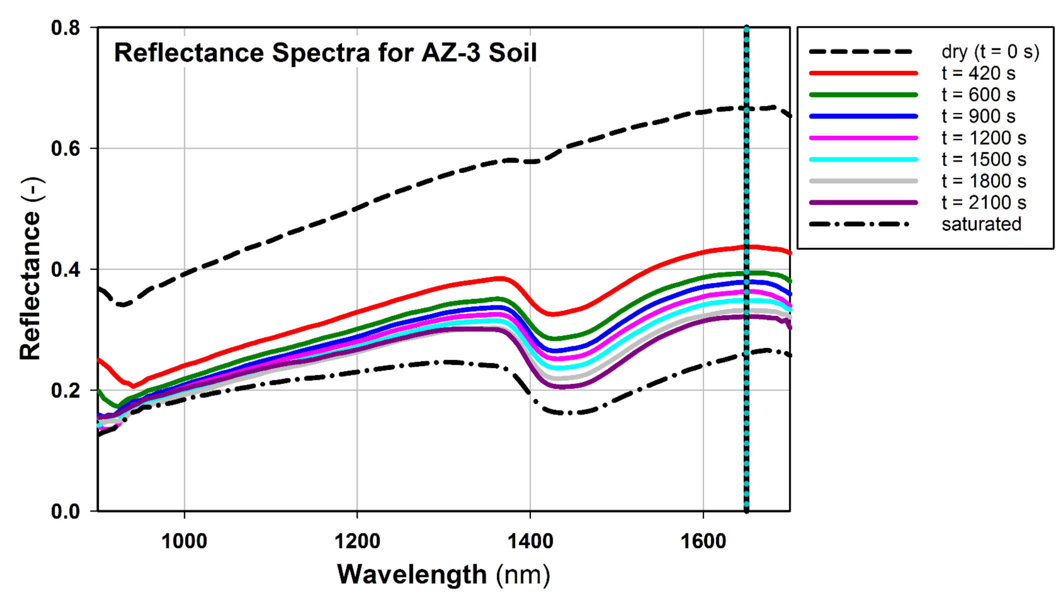

Figure 3: A series of reflectance spectra for AZ-3 soil. Measurements were conducted with the 0.5 cm deep sample container and a syringe pump discharge rate of 0.5 ml min^{-1}.

- Figure 4 depicts high resolution surface soil moisture distribution maps for AZ-3 soil. The maps were generated by converting the hyperspectral observations to moisture content with the *Sadeghi et al. (2015)* model.

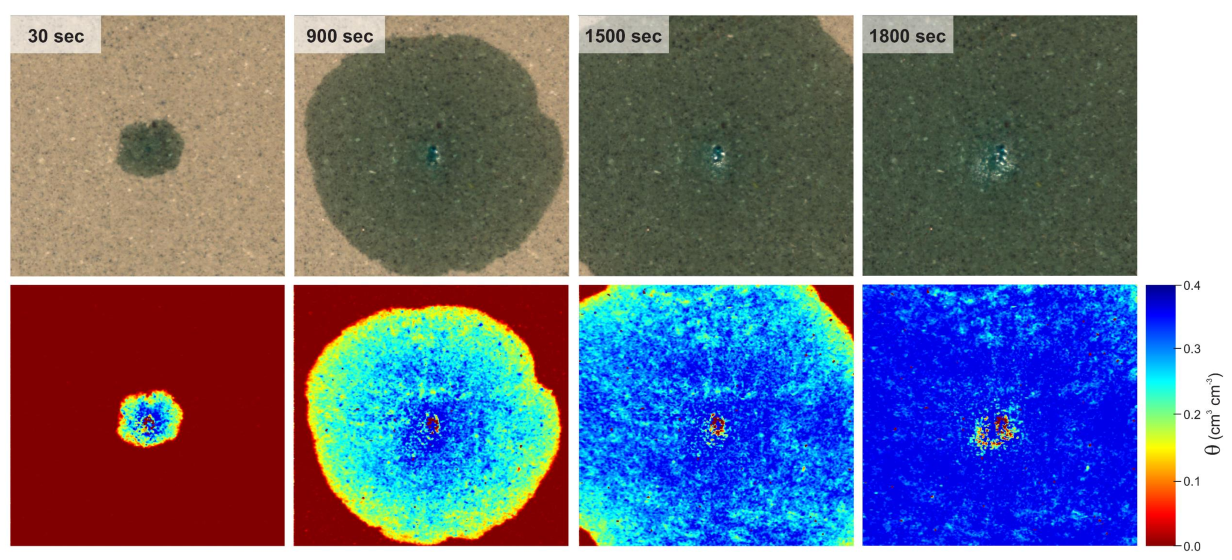

Figure 4: Surface moisture distribution maps for AZ-3 soil.

Preliminary Results - Continued

- The inversely determined hydraulic functions were compared to actual measurements conducted with Tempe cells and a rigid wall constant head permeameter (i.e. K_{sat}) (Fig.5). Especially for AZ-3 soil, the inversion results are very close to the actual measurements. For the AZ-10 and AZ-18 soils the wet end of the soil water characteristic is slightly off. This is most likely due to different compaction densities (i.e. porosities) of the Tempe cell and hyperspectral imaging samples.

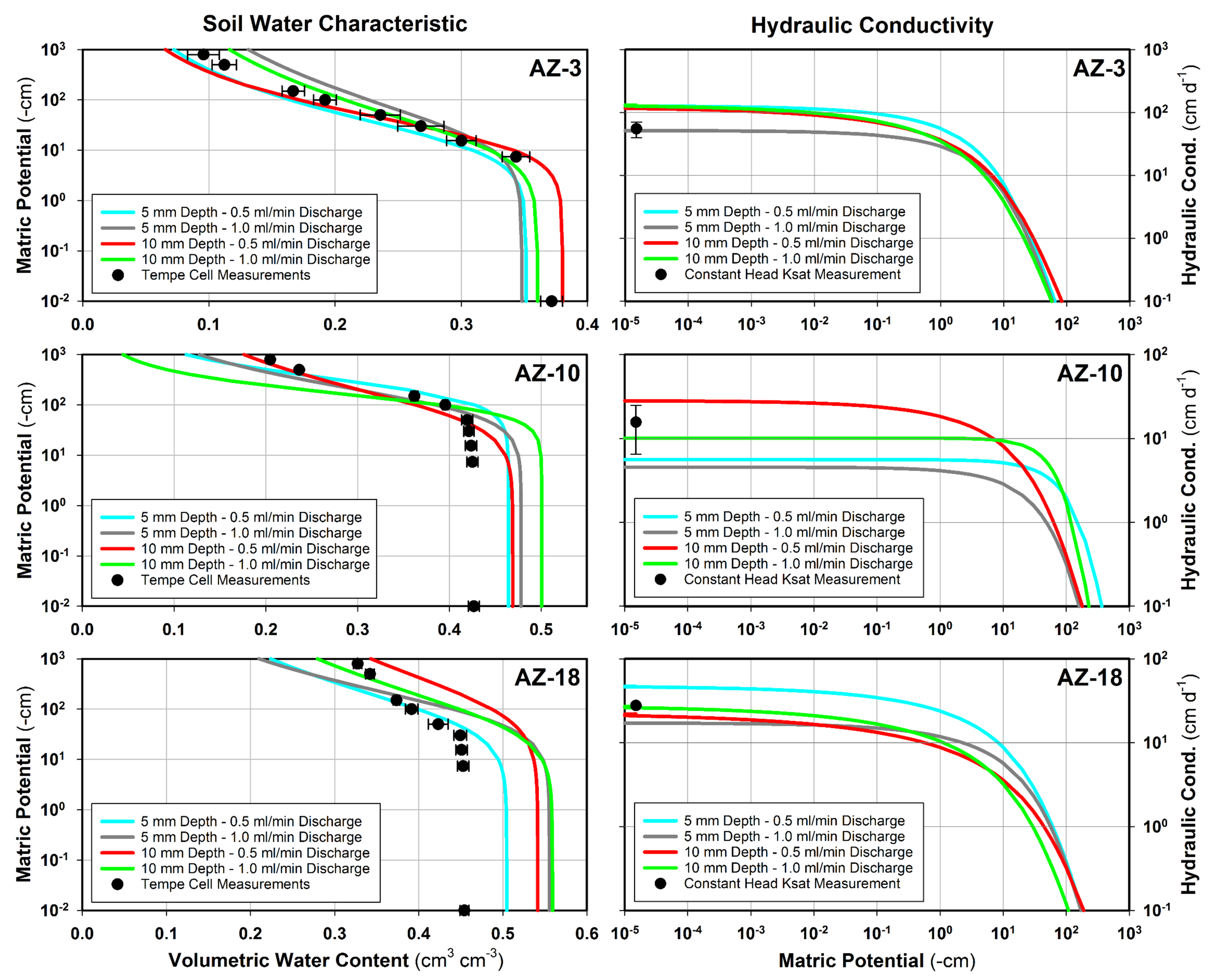

Figure 5: Comparison of inversely derived $\theta(h)$ and $K(h)$ functions with Tempe cell and constant head permeameter measurements.

Conclusions and Ongoing Work

- Obtained results are very encouraging and demonstrate the potential of the presented method for rapid soil hydraulic properties determination (1 to 2 hours versus several weeks).
- In addition, the experiments provide valuable basic knowledge that can be potentially applied for large scale airborne or satellite remote sensing of surface soil moisture.
- We are currently refining the image analysis and inversion procedures to obtain more robust results.
- Furthermore, a comprehensive measurement campaign is underway to apply the refined method to a wider range of soils spanning all textural classes.

References

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