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Integrating tropical soil-calibrated pedotransfer functions with Sentinel-1 backscatter for soil moisture retrieval in soybean and maize systems in Zambia

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Abstract

Accurate characterisation of soil hydraulic properties is critical for understanding and mitigating the impacts of precipitation variability in rainfed maize (*Zea mays*) and soybean (*Glycine max*) systems across sub-Saharan Africa (SSA), where soils act as the primary water reservoir. However, direct measurement of these properties is labor-intensive, time-consuming, and costly. Pedotransfer functions (PTFs) provide a practical alternative by estimating hydraulic parameters from readily available soil attributes. This study assessed the spatial variability of key soil hydraulic properties in soybean–maize systems in Lusaka, Katete, and Kalomo districts of Zambia. Clustered soil sampling was conducted using the Land Degradation Surveillance Framework across 10 fields per location. Locally calibrated PTFs were developed for tropical conditions using an Artificial Neural Network (ANN) trained on the tropical subset of the combined International Geosphere-Biosphere Programme and World Soil Information Service (IGBP-WoSIS/T) datasets. The ANN model demonstrated strong predictive performance, achieving a coefficient of determination (R^2) of 0.84 and a root mean square error (RMSE) of 0.064 $cm^3\,cm^{-3}$ on the test dataset. The PTF was used to estimate soil water retention at matric potentials corresponding to 10 pF values: 0.0, 1.0, 1.5, 2.0, 2.3, 2.5, 3.0, 3.4, 3.7, and 4.2. These estimates enabled the generation of continuous soil water retention curves (SWRCs) using the van Genuchten model, from which key hydraulic properties, including residual water content, porosity, and available water capacity (AWC), were derived. These parameters were subsequently used to normalise Sentinel-1 radar backscatter for soil moisture retrieval, reducing dependence on laboratory-based measurements. Soils across the three study sites exhibited substantial variability in texture, organic carbon, and bulk density, resulting in AWC values ranging from 0.15 to 0.25 $m^3\,m^{-3}$. Soil moisture estimates derived from normalised Sentinel-1 backscatter showed variable but meaningful agreement with *in situ* TMS-4 soil moisture probe measurements, with R^2 values ranging from 0.20 to 0.80 across the maize and soybean fields. This study demonstrates the potential of integrating locally calibrated PTFs with remote sensing data to improve soil moisture estimation in data-scarce, agricultural systems, supporting more informed water management and precision agriculture in SSA.

Keywords: Artificial Neural Network, pedotransfer functions, Rainfed agriculture, Sentinel^{-1}; Tropical soils, Soil moisture retrieval, Soil water retention, Zambia

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