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Towards rapid 3D soil moisture mapping with multiple on-the-go proximal sensors

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Abstract: Soil water content (SWC), or soil moisture (SM), as a major limiting factor of dryland cropping system, has consistently been a central focus in agricultural soil research. The emergence and commercialization of probe, remote sensing and proximal sensing techniques have enabled growers to access accurate and site-specific information about soil water content at a lower cost and fewer technical barriers.

On-the-go proximal sensors are easily used for fieldwork and allow for periodic data collection during operations without interrupting workflow. On-the-go electrical magnetic induction sensors (EMI) and gamma-ray spectrometers (GRS) have been extensively used for estimating soil water content. Gamma ray sensors measure gamma emissions in the top 40 cm of the soil which is reflected as a concentration of potassium (K), uranium (U) and thorium (Th) isotopes. EMI sensors measure soil apparent electrical conductivity (ECa) which is positively correlated with soil moisture. A common EM sensor, DUALEM-21, reaches a sensing depth of approximately 0.5 m and 1 m in the perpendicular geometry (PRP), and 1.6 m and 3.2 m in the horizontal co-planar (HCP), at coil separation of 1 m and 2 m, respectively. L-band microwave radiometers retrieve soil moisture to an effective depth of 5 cm by measuring the soil brightness temperature in L-band and deriving its dielectric constant. In recent years, an on-the-go version of this technology has been developed but it is mostly used for surface soil moisture retrieval using a single instrument. There is potential to fuse L-band and other proximal sensors to establish accurate site-specific soil moisture profile in multiple depths.

This work aims to investigate whether a machine learning-based solution that fuses proximal sensing data at different depths can accurately estimate the soil moisture profile and demonstrate spatial generalizability. This study utilises three tractor-mounted proximal sensors (EMI, GRS, and L-band radiometer) to measure soil moisture at the surface and estimate the soil moisture profile across five depth intervals from 0 to 100 cm. In our preliminary research, we assessed the importance of all covariates and found that the strongest correlations were observed between topsoil moisture (0–5 cm and 5–15 cm) and measurements from the L-band (brightness temperature), GRS (total count), and EMI sensor (EM 100). Correlations with all three instruments were weaker at greater depths. The results also demonstrate that, using a linear regression model, the optimal combination of covariates from the three proximal sensors can achieve an RMSE below 0.04 m^3/m^3 across the profile.

Further research will utilise two machine learning methods to improve modelling accuracy, including random forest (RF) and Extreme Gradient Boosting (XGBoost). The input features include L-band (brightness temperature), gamma-ray (K, U, Th concentration and total dose), EMI responses measured in PRP and HPC, using coil separations of 1 m and 2 m, respectively. The estimated soil moisture profile will be evaluated against measurements from 6 probes and 27 core samples at four depths from 0–100 cm. The spatial generalizability will be examined by a block-based Leave-One-Out Cross-Validation (LOOCV), in which spatial blocks are iteratively left out for validation. The ultimate goal of this study is to develop a rapid and reliable three-dimensional soil moisture mapping approach using on-the-go proximal sensors, without the need for prior calibration or destructive sampling.

Keywords: *Proximal sensors, data fusion, machine learning, L-band, soil moisture mapping*

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