Linking remotely sensed multispectral data to large-scale electromagnetic induction measurements for soil parameter prediction by means of multiple linear regression kriging

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Soils provide vital resources and different techniques have been proposed to characterize soil inherent processes. We use non-invasive high-resolution multi-configuration electromagnetic induction (EMI) that senses multiple depths of investigation (DOI), sparse soil sampling, and satellite derived normalized difference vegetation index (NDVI) data to predict top- and subsoil properties by means of multiple linear step-wise regression-kriging (RK). The study determines the most descriptive covariates as well as the optimal number and soil sampling calibration locations at a 4 ha field located in the Rur River valley (Germany) with a distinct underlying fluvial geomorphology. The EMI data were acquired for nine DOIs using simultaneously two fixed-boom multi-coil EMI instruments. A three- and a six-coil EMI instrument respectively used vertical coplanar and horizontal coplanar coils to provide shallow and deep DOIs between 0.25 m and up to 2.70 m depth. Differential GPS systems delivered coordinates for each instrument. Two multispectral satellite images showed NDVI patterns similar to those observed with ground-based EMI and soil sampling data of 45 probing locations.

The relationships between EMI, NDVI, texture, and water content were explored by RK and used to upscale the soil properties. To discern the explanatory variables and to obtain the best prediction accuracy iteratively, the correlation coefficient (r) and root mean square error were computed. We found that RK outperformed ordinary kriging due to the fairly linear covariate and soil property correlation. Stepwise reducing the 45 soil samples resulted in 12 minimum samples that can be used together with different EMI DOI data to fully describe soil heterogeneity with a 1×1 m resolution for five depth ranges down to 1 m. The EMI data were the most explanatory covariates and best predictions were obtained using DOIs similar to the soil sampling depth for silt ($r = 0.5$-0.7) and clay ($r = 0.4$-0.6). However, adding NDVI improved predictions only in 4 out of 25 cases. The low correlation between NDVI and the deepest sensing HCP coils (DOI ~ 1.5 to 2.7 m) showed that the deeper subsoil had lower impact on plant performance at this test site probably due to the shallow buried fluvial system depth and/or shallow grass rooting depth. Consequently, EMI data combined with sparse soil samples provide high-resolution soil property maps. Improvements are expected when using non-linear (3D) regression models that consider spatial correlation and system metrics such as data entropy.