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Three-dimensional mapping of soil organic carbon and soil water content with proximal soil sensing data

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Soil organic carbon (SOC) and soil water (SW) content are closely associated to the availability of nutrients and plant growth, influencing soil functions with important implications for food production and carbon cycling. To maintain these functions, knowledge of the spatial variability and quantity of SOC and SW is crucial. Derived information can be generated using machine learning algorithms within the scope of digital soil mapping (DSM). Most approaches, however, focus on the horizontal domain. Yet, distribution and variability within the soil continuum should be addressed in the vertical domain as well. Multiple horizontal layers may be interpreted three-dimensionally, but show a limited vertical resolution and, therefore, lack volumetric information. In comparison, spatially predicted depth functions comprise volumetric information with high vertical resolution. In this study, we calculated the sample distribution of 25 profiles on an agricultural field located in the Elbe floodplain in Saxony-Anhalt with weighted conditioned Latin Hypercube Sampling (wecLHS) based on geophysical measurements from six electromagnetic induction (EMI) sensors with different intercoil spacing and a gamma-ray spectrometer. Soil samples were taken in four depths from 0 to 60 cm depth. The tested profile depth functions are 2^{nd} degree polynomials as well as logarithmic and exponential functions. The coefficients of depth functions were modelled spatially with the geophysical measurements as environmental covariates using Cubist, random forests (RF) and support vector machine (SVM). The final 3D maps were calculated by solving the depth functions at any grid point with 5 cm vertical resolution. For evaluation, we used repeated cross-validation and compared the 3D predictions with multi-layered horizontal predictions directly. The major hypothesis of this work is that 3D models based on geophysical measurements with depth dependent sensitivities yield stable predictions of SOCand SW over multiple depth increments. The main findings are that RF on 25 profiles was superior to SVM and Cubist in the spatial modelling of coefficients (SOC: R^2 = 0.45; SW:R^2 = 0.68 in cross-validation). RF yielded the best 3D predictions, remaining stable over multiple depths for SOC (mean R^2 = 0.79); Cubist yielded the best model for SW(mean R^2 = 0.9). Overall, 3D predictions from geophysical measurements provide high and stable accuracies throughout depths. The correspondence between 3D and multi-layered 2D predictions of SOCin all depth increments was high (SVM: R^2 = 0.95; RF: R^2 = 0.94). Therefore, we recommend the spatial prediction of depth functions for 3D soil property mapping on field scale.