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Combining hyperspectral imagery and legacy measured soil profiles to map subsurface soil properties in a Mediterranean area (Cap-Bon, Tunisia)

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Previous studies have demonstrated that Visible Near InfraRed (Vis-NIR) Hyperspectral imagery is a cost-efficient way for mapping soil properties at fine resolutions (∼5m) over large areas. However, such mapping is only feasible for soil surface since the effective penetration depths of optical sensors do not exceed several millimetres. This study aimed to extend the use of Vis-NIR hyperspectral imagery to the mapping of subsurface properties at three intervals of depth (15-30 cm, 30-60 cm and 60-100 cm) as specified by the GlobalSoilMap project. To avoid additional data collection, our basic idea was to develop an original Digital Soil Mapping approach that combines the digital maps of surface soil properties obtained from Vis-NIR hyperspectral imagery with legacy soil profiles of the region and with easily available images of DEM-derived parameters.

The study was conducted in a pedologically-contrasted 300km^2 cultivated area located in the Cap Bon region (Northern Tunisia). AISA-Dual Vis-NIR hyperspectral airborne data were acquired over the studied area with a fine spatial resolution (5 m) and fine spectral resolution (260 spectral bands from 450 to 2500nm). Vegetated surfaces were masked to conserve only bare soil surface which represented around 50% of the study area. Three soil surface properties (clay and sand contents, Cation Exchange Capacity) were successfully mapped over the bare soils, from these data using Partial Least Square Regression models (R2 > 0.7). We used as additional data a set of images of landscape covariates derived from a 30 meter DEM and a local database of 152 legacy soil profiles from which soil properties values at the required intervals of depths were computed using an equal-area-spline algorithm.

Our Digital Soil Mapping approach followed two steps: i) the development of surface-subsurface functions – linear models and random forests - that estimates subsurface property values from surface ones and landscape covariates and that were calibrated over the set of legacy measured profiles and ii) the application of these functions over the study, using as input the hyperspectral-derived digital soil maps of surface soil properties and the images of landscape covariates. Error propagation in these two steps was addressed using a Monte Carlo approach for estimating the mapping uncertainties.

The main results were as follows: i) fairly satisfactory (R2 between 0.55 and 0.81) surface-subsurface functions were obtained for predicting soil properties at 15-30 cm and 30-60 cm whereas predictions at 60-100 cm were less accurate (R2 between 0.38 and 0.43) ii) linear models generally outperformed random-forest ones in developing surface-subsurface functions iii) Due to error propagations, the final maps of subsurface soil properties captured from 1/3 to 2/3 of the total variability with a significant decrease of performance with prediction depth, iv) these maps brought significant improvements from the existing soil maps of the region and showed soil patterns that were largely in accordance with the local pedological knowledge.