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Applications of infrared spectroscopy to quantify and characterize soil organic carbon

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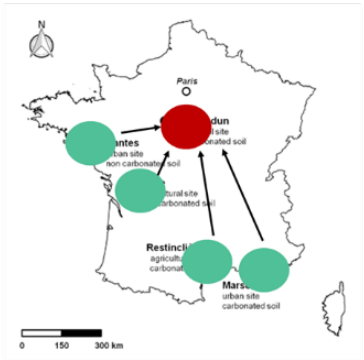
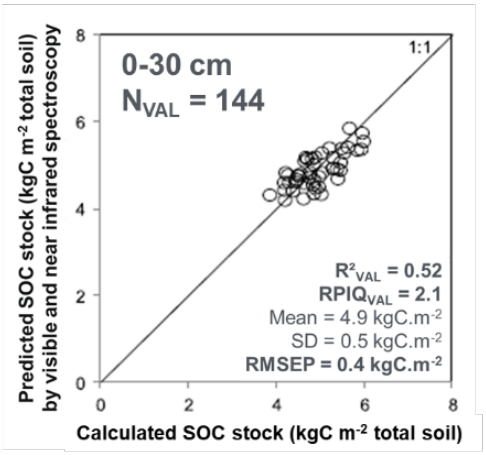
Abstract:
Soil organic carbon (SOC) contributes to the maintenance of soil physical, chemical, and biological functions. However, the conventional methods for (i) quantifying SOC stock (in kgC m^{-2} for a given soil layer), which is the product of SOC concentration (gC kg^{-1}) by volumetric mass (kg dm^{-3}), and (ii) identifying SOC fractions, which provide information about SOC dynamics and stability, are time-consuming and tedious.
The use of infrared (IR) spectroscopy has been developed to quantify soil properties (Janik et al., 1998, *doi: 10.1071/EA97144*; Viscarra Rossel et al., 2006, *doi: 10.1016/j.geoderma.2005.03.007*; Stenberg et al., 2010, *doi: 10.1016/S0065-2113(10)07005-7*). This is a rapid, non-destructive and reproducible approach, that can be used in both laboratory and the field, with low unit cost, and no consumables or waste. Moreover, various properties can be determined from a single spectrum. Two spectral domains are often used: the near IR (800-2500 nm) and the mid-IR (2500-25,000 nm). Most current uses of IR spectroscopy are based on calibrations built by multivariate regressions on calibration samples characterized both conventionally (e.g., by dry combustion for SOC) and spectrally. These calibrations can then be applied to new samples to predict the variable of interest (e.g., SOC) using their spectrum. Thus, the variable of interest is not measured by IR spectroscopy but predicted, with an associated uncertainty.
Many works demonstrated that IR spectroscopy allows accurate prediction of SOC concentration (gC kg^{-1}), at different scales (plot, region, country). Better predictions with mid- than near IR have often been reported for soil samples from temperate regions, finely ground at 0.2 mm. On the contrary, better predictions with near IR have often been reported for tropical and/or 2-mm sieved soil samples. Current development of large calibration databases for SOC concentration, and progress in spectral data analysis pave the way for wide use of IR spectroscopy, which should help solving the SOC data crisis. Recent works also showed an interest of IR spectroscopy for directly predicting SOC stocks, without having to determine SOC concentration and volumetric mass (except for calibration), but corresponding calibration databases are still limited to date. Predictions of SOC stock are more accurate in general when using spectra of dry soil < 2 mm than using field spectra, except when coarse particle content (> 2 mm) is high and varies between samples. Furthermore, several studies showed the IR spectrum of bulk soil could be used for predicting SOC distribution among its fractions, for instance particle size fractions, and corresponding calibration databases are being developed. Thus, IR spectroscopy facilitates SOC characterization, and increases the value of conventional analyses carried out on some samples by using them for predictions on other samples.
In short, IR spectroscopy has strong potential for supporting better SOC monitoring. This communication proposes an overview on the benefits of IR spectroscopy for rapid, low-cost quantification of SOC in terms of concentration and stock, and of its particle size fractions.

Annex

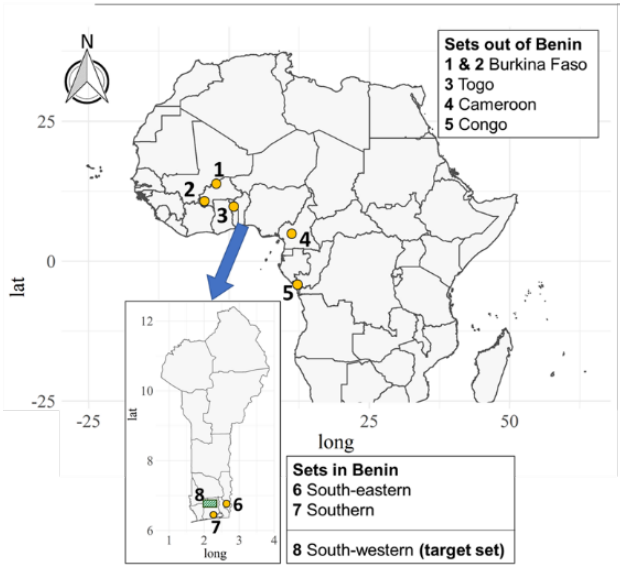
Prediction of SOC stock (kgC m^{-2}) in French sites using near IR spectra of soil < 2 mm (four calibration sites in green, one validation site in red)

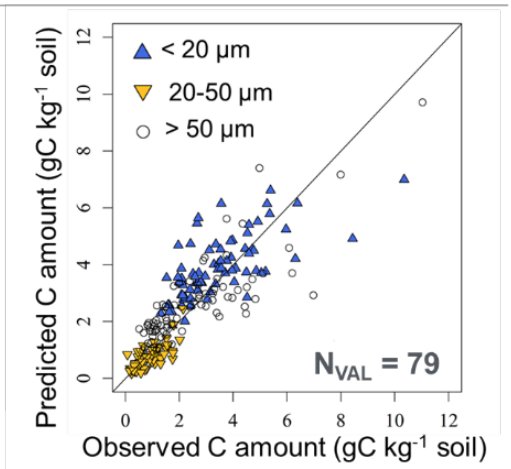




Cambou, A., Allory, V., Cardinael, R., Carvalho Vieira, L., Barthès, B.G., 2021. Comparison of soil organic carbon stocks predicted using visible and near infrared reflectance (VNIR) spectra acquired in situ vs. on sieved dried samples: Synthesis of different studies. Soil Security 5, 100024. DOI: 10.1016/j.soisec.2021.100024

Prediction of SOC particle size distribution in west-African sites using near IR spectra of bulk soil (seven calibration sites in yellow, one validation site in green)





RMSEP (< 20 µm) = 1.2 gC kg^{-1} soil < 2 mm
RMSEP (20-50 µm) = 0.3 gC kg^{-1} soil < 2 mm
RMSEP (> 50 µm) = 1.1 gC kg^{-1} soil < 2 mm

Cambou A., Houssoukpèvi I.A., Chevallier T., Moulin P., Rakotondrazafy N.M., Fonkeng E.E., Harmand J.-M., Aholoukpè H.N.S., Amadji G.L., Tabi F.O., Chapuis-Lardy L., Barthès B.G., submitted. Quantification of soil organic carbon in particle size fractions using a near infrared spectral library in West Africa.