Laboratory, field and airborne spectroscopy for monitoring organic carbon content in agricultural soils

A. Stevens, B. van Wesemael, B. Tychon, D. Rosillon, H. Bartholomeus, E. Ben Dor
Introduction

Why SOC monitoring?

Why using reflectance spectroscopy?

- High spatial variability of SOC → high sampling density required
- Traditional sampling techniques are time consuming
- High potential for rapid in situ measurements and SOC mapping
Introduction
Introduction

**Spectral Library Viewer**

- **Simulated Landsat TM Spectrum**
- **Kaolinite Laboratory Spectrum**

Value (Offset for clarity) vs. Wavelength (plot details)
Introduction

Objectives

- Compare the predictive ability of these three types of sensors for SOC determination using Partial Least Square Regressions
- Evaluate the stability of calibrations
- Evaluate the potentialities for SOC monitoring and mapping
Methodology

- Study areas

[Map of Belgium showing study areas: Flemish Region, Wallonia, Ardennes, Tintigny 2005, Attert 2003, Ortho 2003, Jura]
Methodology

Spectral measurements

- Imaging Spectroscopy:
  - In 2003: CASI sensor (405 to 950 nm, 96 bands)
  - In 2005: AHS sensor (400 to 2500 nm, 80 bands)

Other constraint: small vertical gradient in SOC
Methodology

- Portable Spectroscopy: Analytical Spectral Device (ASD: 350-2500 nm)
Methodology

- Laboratory spectroscopy: spectral measurement of sieved (2 mm) and air-dried soil samples with the ASD contact probe

### Laboratory analyses: Soil Organic Carbon (g kg$^{-1}$)

- **Bellefontaine 2003**: Mean = 37, SD = 4.9, Min = 5.7, Max = 22.8
- **Ortho 2003**: Mean = 65, SD = 3.5, Min = 19.9, Max = 37.3
- **Tintigny 2005**: Mean = 99, SD = 2.7, Min = 5.9, Max = 22.1

- **All campaigns 201**: Mean = 17.7, SD = 7.3, Min = 5.7, Max = 37.3
Methodology

Data transformation before statistical analysis

- Removing vegetation influence (spectra having a NDVI > 0.3)
Methodology

Data transformation before statistical analysis

- Reduce the noise with standard pre-treatments (Savitsky-Golay, 1st and 2nd gap derivative, etc.)

![Graphs showing absorbance and first derivative over wavelength](image-url)
Methodology

- Relate SOC and spectra using Partial Least Square Regressions (PLSR)
- Select the best model (pretreatment) on the basis of their Ratio of Performance to Deviation (= RMSEP / SD)
- To test the stability of the calibrations, we joined current ASD field measurements with those of previous campaigns (CASI 2003) producing a dataset of 201 samples with varying carbon content, texture, soil surface condition and soil types
Results

![Graphs](image-url)
Results

Portable Spectroscopy
Imaging Spectroscopy
Laboratory Spectroscopy

Laboratory Spectroscopy

N = 112
SECV = 1.24
RPD = 2.01
Results

Stability across time and space: validation results

- Calibration
- Validation

- $N_{\text{cal}} = 101$
- $N_{\text{val}} = 99$
- $SEC = 1.10$
- $SEP = 11.91$
- $RPD_{\text{cal}} = 6.97$
- $RPD_{\text{val}} = 0.23$
- $Bias_{\text{val}} = 0.43$
Results

- Stability across time and space: cross validation
Summary of results

- There is a decrease in predictive ability from laboratory spectroscopy to remote-sensing due to:
  - Difference in sensor characteristics (number of spectral bands);
  - Uncontrolled measuring conditions (light source quality, soil surface conditions)
- The ASD gives accuracies (± 0.1% C) that are similar to a routine analytical method (Walkley & Black)
- Calibrations are currently site-specific and partly fail to predict, under a proper independent validation, samples belonging to another study area
Results

Summary of results

Further needs:

- More measurements (spectral libraries)!
- Standard spectral measurement protocols in the field (surface conditions required, etc.)
Monitoring of soil carbon

- Why VNIR spectroscopy offers a great potential in the context of soil monitoring?

- Minimal Detectable Difference (MDD): How many samples are required to demonstrate a given change in SOC stocks?
  - SOC stock change after management change are $\leq 2 \text{tC ha}^{-1} \text{y}^{-1}$ (Freibauer et al., 2004)
  - After 3-5 year, it corresponds to $\pm 5 \text{tC ha}^{-1}$
At the field scale, the number of samples required to detect such a change ranges from 7 to 129 samples, depending on the intra-field variability.

Spectroscopic techniques can significantly reduce the MDD between SOC stocks (i.e., reducing the confidence limit of the mean) by increasing the number of samples.
Soil Mapping

CASi

Legend
% Carbon
High: 4.19
Low: 1.95
Soil Mapping

Carbon content (g/kg)

- 0 - 10
- 10 - 11
- 11 - 12
- 13 - 14
- 14 - 16
- 16 - 20

Sampling point

Coordinate system: WGS 84 - UTM 31N

AHS
Conclusion

- Accuracies achieved by the ground measurements (Laboratory and Portable Spectroscopy) are comparable to the one of a standard analytical method (Walkley-Black) and they can thus be used for monitoring studies where their speed is a valuable advantage.

- Imaging spectroscopy, appears, for the time being, not able to predict SOC with an acceptable accuracy due to its low SNR and problem to achieve true spectral information. Nevertheless, the greater potential lies in this technique and more efforts have to be put in spectrum calibration.
Merci pour votre attention !