SOC3D: three dimensional soil organic carbon monitoring using VNIR reflectance spectrometry

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Why Soil Organic Carbon (SOC)?

Environmental issues:
• Soil is the largest pool of terrestrial carbon.
• Land use change and management influence SOC stocks.
• Large sink of atmospheric C (due to large size and long residence time).
• Climate change.

Agricultural issues:
• Soil fertility and quality.
Why Soil Organic Carbon (SOC)?

Some challenges:

- Large spatial variability and slow evolution of soil C over time.
- Large number of samples required prove significant changes over time.
- Sampling and analysis are too costly for treating large number of samples (Smith, 2004).

A potential solution:

• Increase the number of observations with cheaper methods of analysis
Why Soil Organic Carbon (SOC)?

From **SOC concentration (g C kg\(^{-1}\) soil)**

to

**SOC stock (kg m\(^{-2}\)) = SOC (kg kg\(^{-1}\)) × Soil density (kg m\(^{-3}\)) × thickness (m)**

Develop cost effective tools for SOC monitoring at field and regional scales
Why Soil Organic Carbon (SOC)?

From SOC concentration \((g \, C \, kg^{-1} \, soil)\)

to

SOC stock \((kg \, m^{-2}) = SOC \,(kg \, kg^{-1}) \times \) Soil density \((kg \, m^{-3}) \times \) thickness \((m)\)

Develop cost effective tools for SOC monitoring at field and regional scales

± 1 % C

± 4 % C
APEX sensor (Airborne Prism EXperiment)

Overflight 16.09.2011, 7 flight lines, total number of 39 tiles

Hyperspectral data in 288 channels between 400 nm and 2500 nm with a 2.8 m spatial resolution
APEX spectral data of bare soil

SOC3D: three dimensional soil organic carbon monitoring using VNIR reflectance spectrometry
Analysis of the spectral differences between bare fields in overlapping areas
SOC3D: three dimensional soil organic carbon monitoring using VNIR reflectance spectrometry
Basic strategy

**2D**

APEX DATA + (Geomorphic features)

**3D**

Geomorphic features

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Our study area comprises a total surface of \( \sim 23 \text{ km}^2 \) (\( >1000 \) fields)

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**3. Methodology**

- VNIR imaging spectra (APEX data)
  - Delimitation of the study areas...
  - Maximum likelihood classification
  - Identification of the bare fields

Surface (2D) modeling strategy
VNIR imaging spectra (APEX data)

Identification of the bare fields

Maximum likelihood classification

Delimitation of the study areas...

Validation samples...

44 sampling locations randomly selected

SOC determination (lab. analysis)

Calibration samples...

90 sampling locations selected based on the VNIR and terrain variability*

SOC determination (lab. analysis)

* Terrain or geomorphic features (e.g. elevation, slope, curvature, etc.) at the respective sampling locations
Calibration sampling: Select a set of samples to cover properly both the VNIR and geomorphic variability.

Validation sampling: Select a set of independent samples to validate both the SOC models and SOC maps derived from the models.
Identification of the bare fields

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SOC modeling...

Approaches

Regression algorithms

Accuracy parameters

SOC = f(VNIR, ...) + ε

PLS

Training RMSE

SOC = f(Geomorphic F*, ...) + ε

Random forests (RF)

Training R²

SOC = f(VNIR, Geomorphic F*, ...) + ε

RF + kriging

* Terrain or geomorphic features (e.g. elevation, slope, curvature, etc.) at the respective sampling locations

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**Problem**

Poor direct (univariate) correlation between each band and SOC concentration

**Proposed solution**

Data mining approach to learn and exploit the multivariate relationship between SOC and VNIR features

\[
SOC = f(VNIR^*, \ldots)
\]

*VNIR = \{R_{350nm}, \ldots, R_{2500nm}\}
VNIR imaging spectra (APEX data)

Identification of the bare fields

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Selection of the best model

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SOC MAPPING ACCURACY

* Terrain or geomorphic features (e.g. elevation, slope, curvature, etc.) at the respective sampling locations

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Sub surface (3D) modeling strategy

From discrete to continuous depth information

Logistic SOC depth function

\[ OC = b - \frac{c - b}{1 + \exp(a \times (depth - d))} \]

\( b \): SOC at the top layer

Parameter given by the SOC predicted using the VNIR data

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Sub surface (3D) modeling strategy

\[ OC = b - \frac{c - b}{1 + \exp(a \times (depth - d))} \]

- **b**: SOC at the top layer
- Parameter given by the SOC predicted using the VNIR data
- \( a = f \) (Terrain attributes, ...)
- \( b = \text{SOC}_{0-10} \)
- \( c = f \) (Terrain attributes, ...)
- \( d = f \) (Terrain attributes, ...)

Spatial models

**SOC3D**: three dimensional soil organic carbon monitoring using VNIR reflectance spectrometry
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1. Introduction  
2. APEX data  
3. Methodology  
4. Preliminary results  
5. Concluding remarks

Agro-pedological regions

Legend

High : 2.37877  
Low : 1.97928

Surface (2D) SOC mapping

SOC, %

4.58

0.88
### Features

<table>
<thead>
<tr>
<th></th>
<th>Algorithm</th>
<th>Training</th>
<th>Validation</th>
<th></th>
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<td></td>
<td></td>
<td>R2</td>
<td>RMSE</td>
<td>R2</td>
<td>RMSE</td>
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<td>Spectra</td>
<td>PLS</td>
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<td>Terrain</td>
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<td>RF</td>
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<tr>
<td>Terrain+Spectra</td>
<td>RF+Kriging</td>
<td>0.54</td>
<td>0.54</td>
<td>0.72</td>
<td>0.57</td>
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</tbody>
</table>

### Validation plots

- **Spectra**
  - PLS

- **Terrain**
  - RF

- **Terrain+Spectra**
  - RF

- **Terrain+Spectra**
  - RF+Kriging

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Spatial prediction of SOC using Random Forests – kriging

Example:

- **SOC, %**
  - High: 2.37877
  - Low: 1.97928

- **Legend**
  - High: 2.37877
  - Low: 1.97928

- **Co**: 0.029
- **C**: 0.026
- **Range**: 145 m
- **C/(C+Co)**: 0.53

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• The selection of the sampling locations (for models calibration) should ensure a good coverage of the VNIR and geomorphic variability in order to obtain reliable models of SOC.

• The strategy for the selection of the sampling locations is crucial, especially when the number of observations is limited.

• The integration of imaging spectrometry and geomorphometry in combination with a sophisticated spatial data mining technique considerably improve the spatial prediction of SOC content.

• We consider that the prediction performance of the models could be improved by increasing the number of observations.

• The improvement on the APEX data correction could improve the prediction performance of the VNIR models.
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Thank you for your attention

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