Is the apportioning methodology used for carbon stock accounting in agricultural soils correct?

M. I. Khalil and B. A. Osborne

UCD School of Biology and Environmental Science
UCD Earth Institute

5th iLEAPS Science Conference “Understanding the impact of land-atmosphere exchanges” Oxford, UK, 11-14 September 2017
Soils & Soil Organic Matter

- Storehouse of atmospheric CO$_2$: C sequestration
- Source of GHGs: CO$_2$, CH$_4$ and N$_2$O
- Soil Quality/Health: Fertility and Productivity
International Agreements

UNFCCC, IPCC, COP, UNEP, EEA, etc.

Paris agreement (COP 21):

To keep global temperature <2°C -

- Enhanced GHG mitigation measures
- A reduction in assessment uncertainties
- Better quantified sinks, and
- The tailored use of different offsetting mechanisms
Annex-I country (UNFCCC/IPCC):

Obligation for accounting and reporting GHGs to UNFCCC – precise, verifiable estimation of SOC for

\[ \text{Ag} + \text{LULUCF} = \text{AFOLU} \]

Article 3.3: Afforestation, deforestation & reforestation

**Article 3.4:** Agricultural soils, covering soil C balance regardless of LULUC and inputs

- GHG offset/trade-off relations
- Carbon credits benefits
SOC accounting: Measurement and Estimation

SOM/SOC Measurement

Sampling error
- Topography
- Land use and management
- Number of samplings
- Time of samplings

Preparation error
- Compositing
- Homogenization
- Grinding, screening, sifting, storage

Analytical error
- QA/QC: Standard methods
- Org + Inorganic = Total
Soil Mass-Volume-Depth: A basis to estimate SOC changes over time

Principal structure and soil profile sampling scheme (Stolbovoy et al., 2007)

Soil profile sampling scheme and SOC monitoring network (Goidts et al. 2009)
Factors: Tillage, compaction, shrinking/swelling, etc. (Lee et al., 2009)

A difference in interpretation when using depth from the soil surface vs. soil mass per unit area (Wuest 2009).
Approaches for the estimation of SOC content

Common approach: Constant depth (CD)

Dry weight of soil samples – depth wise (soil auger/probe sampling) in percentage.

Proposed approaches:

1. Mass-Volume Control (MVC)

Calculating potential effects of processes that alter V and/or M on calculated values for ΔC and other soil characteristics.

Differences in volume sampled (L) when using the CD, EM and VMC methods to measure changes in characteristics between two points in time (t1 = initial, and t2 = final). (Sollins and Gregg, 2017)
2. Equivalent Soil Mass (ESM):

With bulk density: Dry weight of soil samples – area/volume and depth (auger and core sampling).

SOC density (mass by area):

\[
SCD_{site} = \sum_{layer=1}^{j} (SOC_{content} \times BulkDensity \times Depth \times (1 - frag))
\]

Without bulk density: Dry weight of soil samples – area/volume and depth (soil auger/probe sampling) (Khalil, 2012; Wendt & Hauser, 2013).

Error bias induced by quantifying SOC stocks at fixed depths with bulk density differences (Wendt & Hauser, 2013).
ESM by volume/area considering factors influencing soil depth and volume such as moisture, temperature and SOC content could be simpler and also provide best estimate.

SOC stock (mass only):

\[ SOC_{\text{reference}} = SCD_p \times A_p \]

Changes in SOC stock:

\[ \Delta SOC_{\text{stock}} = SOC_{\text{new}} - SOC_{\text{refstock}} - f_{\text{org}} - f_{\text{lim}} \]

SOC often reported as a percentage makes it difficult to assess SOC density/stock and its changes and that mass by volume should be reported along.
In Tier 1, the IPCC proposes % value to use as a SCF for application across key ALU, managements and inputs.

Based on SCF factors, methodologies developed to improve SOC density/stock estimations for national reporting.

Data on LU areas, soil types and SOC were generated by overlaying maps

Khalil and Osborne, 2017
Higher spatial resolution databases, empirical models and GIS approaches provided robust estimates of SOCp/s (Tier-2).

Two phases, Exponential 3P models:
Grassland = 0.080*exp(-0.094*100)+0.002
Rough grazing = 0.081*exp(-0.106*100)+0.002
Tillage = 0.141*exp(-0.089*100)+0.011
Rotation (GT) = 0.045*exp(-0.076*100)+0.002

Khalil and Osborne, 2017
However, the SCF factors used to estimate any change in SOC density/stock resulted in highly variable values.

This depends on the amount of carbon present in a particular soil varying, for instance, from <10% in mineral soil to >10-<20% in organo-mineral soil.

Khalil and Osborne, 2017
Average SOCp across, and their average rates of gain regardless of LU and ST.

SOCs balance in 25 years across, and their annual sequestration rate regardless of LU and ST.
As of IPCC SCFs in percentage, the 4% concept is also unable to provide achievable quantity of SOC\(\rho\) in soils having contrasting SOC concentrations. For example:

<table>
<thead>
<tr>
<th>Land use</th>
<th>Soil type</th>
<th>SOC (%)</th>
<th>SOC(\rho) (t C ha(^{-1}))</th>
<th>4%(\rho) Amount (t C ha(^{-1}))</th>
<th>Management/ Input-induced SOC sink (t C ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grassland</td>
<td>Podzols</td>
<td>3</td>
<td>100</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Gleys</td>
<td>5</td>
<td>150</td>
<td>0.6</td>
<td>0.4 or less</td>
</tr>
<tr>
<td></td>
<td>Brown earth</td>
<td>7</td>
<td>200</td>
<td>0.8</td>
<td>0.4 or less</td>
</tr>
</tbody>
</table>

For SOC stock aspects, the 4%\(\rho\) initiative should be more than a concept i.e. quantifiable and achievable one.
Conclusions

For accurate estimations of SOC density/stock, the determination of SOC

- ‘mass by volume’ on an equal soil mass basis,
- in a defined but adjustable soil layer

could be an appropriate approach.

Given QA/QC followed, LU and Management-specific consistency in sampling time is highly important for all methods.
The findings highlight the importance of

- replacing the IPCC apportioning approach, even the 4‰ concept,
- by a ‘mass by area (depth-specific)’ one for more precise estimations.

This includes:

- the sub-categorization of mineral and organic soils,
- calculation of country-specific SCFs for LUs and MP, and
- the estimation of weighting factors for projections.
Acknowledgements

THANK YOU