Equivalent Soil-Mass (ESM) Corrections for Measuring Soil Carbon Change in Agricultural Systems

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Problem

"Fixed-Depth" Comparisons Systematically Mis-Represent Soil Carbon Change

Soil Carbon stocks are quantified as mass per area to a reference depth (EQ 1).

$$SOC_{D,time=t(T/ha)} = SOC_{pct,t} \cdot \frac{BD_{g/cm^3,t} \cdot D_{cm}}{100}$$

This method is biased when used to quantify SOC stock changes when soil bulk density changes between measurements, (EQ 2).

$$SOC_{D,t2} - SOC_{D,t1} \neq SOCsequest_{t1 \to t2}$$

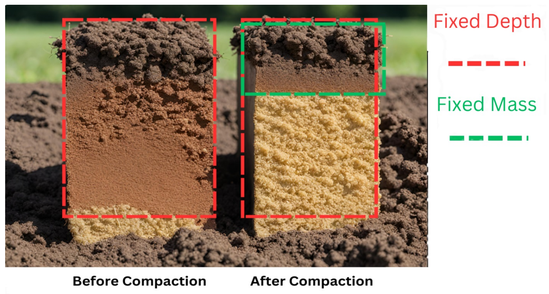

Figure 1. Exaggerated example of soil compaction leading to errors. Fixed-depth method includes additional sub-soil, over-estimating SOC sequestration, and under-estimating change in SOC %.

Solutions: Interpolation

There are several techniques for ESM corrections, all using the same basic steps.

1. At time 0, calculate SOC stocks (Eq 1).
2. At time 0, calculate soil mass to quantification depth.
3. At re-measurement, use measured values of bulk density and SOC to estimate SOC stock to the mass from step 2.

Variations on linear[1] & spline[4] interpolation methods have been proposed; accuracy is improved by measuring soil cores to multiple depths.

Proposed Technique

1. Create a reference curve using profile data the SSURGO soil database.
2. Adjust the curve based on results of a single-depth soil core.
3. Use this curve to interpolate an ESM estimate.

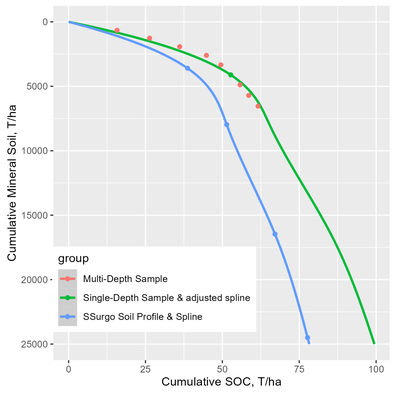

Figure 2. Example ESM curve created from SSurgo data and a single-depth sample.

Data Sources

We validate strategies for ESM estimates using two types of data.

- Plot-level aggregates from 11 scientific papers, both observational and field-trials in the United States, mostly collated by [2].
- High-resolution individual soil-core data from five fields in the mid-west[3].

Leave-one-out (LOO) Validation of Interpolation Methods

First, we test linear and spline-based interpolation methods using Leave-one-out Validation; simulating the exclusion of one depth-layer from a soil profile and predicting cumulative SOC to that depth.

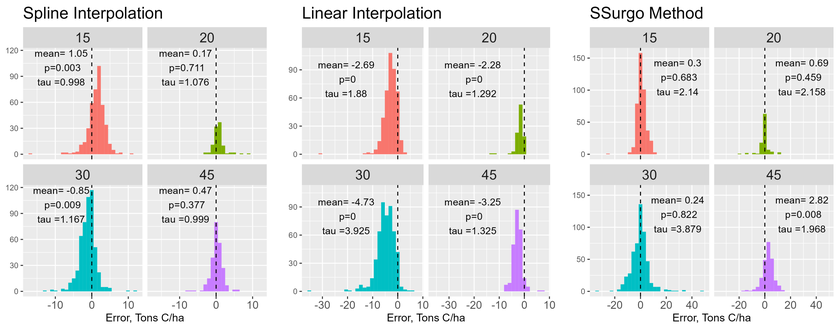

Figure 3. Errors of spline and linear interpolation, using LOO validation, by the depth interpolated (in cm). Spline bias is small and variable between sites, while linear bias is consistently negative. The SSURGO method uses only one depth, and achieves minimal bias, but higher variance.

Simulating ESM comparisons to a 30-cm depth

Methods

Next, we test sampling and interpolation strategies on single or 2-depth soil samples. We use a space-for-time design within each study or site. Whole-field aggregated data are compared to each other field in that study/site. For individual soil cores, each core is compared with the 3 nearest soil cores.

Estimation Techniques

- **Linear:** Single-depth Linear Interpolation
- **Fixed Depth:** Fixed-Depth Calculation of Carbon Stocks at t0 and t1
- **ESM Spline:** Spline-based ESM method
- **2-depth single SOC:** 2-depth core weighed then combined into single sample[4]
- **SSURGO Mass-Correction**: Our method using a single-depth measurement.

Supplemental Information

Scan or click here to see supplemental information.

Comparison Results

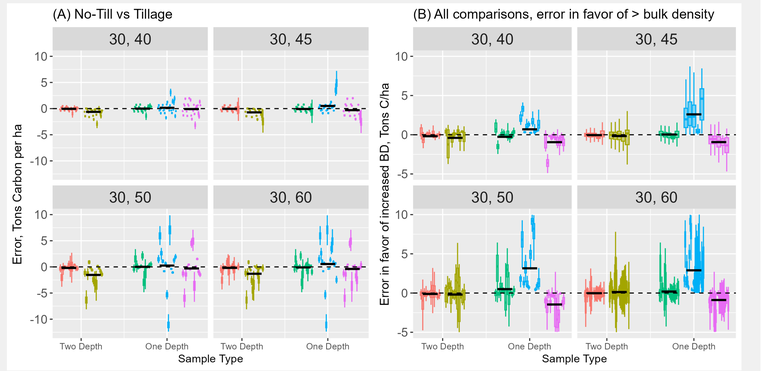

Figure 4. Errors of space-for time SOC comparisons using different quantification methods.

A: ESM errors for comparisons between Tillage & No-Tillage treatments.

B: ESM errors for all comparisons, in the direction of bulk density change.

Data are grouped by the sample depths of the 2-depth data comparison (not all depths are present for each comparison).

Conclusions and Next Steps

- Confirming previous simulation-based work, we find that spline interpolation has lower errors and bias than linear interpolation.
- Spline interpolation, even from two-depth samples has acceptably low bias.
- Using SSURGO-derived reference SOC-accumulation curves appears to give low-bias, low-cost ESM estimates based on a single-depth soil core.

Next Steps:

- Test method on more soil core data, especially high-resolution data.
- Methods for pooling soil-databases & multi-depth cores.

References

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