Synthesis of knowledge on soil carbon spatial patterns across a large subtropical soil-landscape in Southern U.S.

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Abstract

The global soil carbon (C) pool is about five times the biotic pool and about four times the atmospheric pool. Landscapes that sequester large amounts of soil C have potential to mitigate global climate change. However, spatially-explicit assessment of soil C across large regions is limited by the number and density of soil observations to capture the underlying variability across soil-landscape continua. The objectives of this study were to (i) synthesize current knowledge on spatially-explicit soil organic carbon (SOC) assessment using different point and polygon soil datasets collected in Florida, U.S. (~140,680 km^2) and a large mixed-use watershed nested within Florida (~3,580 km^2), and (ii) compare different digital soil mapping methods (aggregation, geostatistical interpolation, and pedo-transfer functions) with different spatial resolutions. The mean SOC across Florida ranged from 13.95 to 47.80 kg/m^2 and total SOC stocks from 1.99 to 6.82 Pg. Total SOC stock in Florida obtained using different data/methods was 4.110 ± 1.01 Pg (mean ± std. error) accounting for approximately 0.13% of soil C on earth assuming that the global pool is 3,250 Pg C. Average SOC in the watershed was 17.49 ± 6.89 kg/m^2, and total SOC was 61.18 ± 24.08 Tg. At both extents, Florida and the watershed, magnitude of differences were found in SOC stocks (means, ranges and absolute values) using different point and polygon soil datasets and aggregation/upscaling methods. Fusing of different soil datasets and methods can help to better capture SOC variability in soil-landscapes.

Key Words

Soil organic carbon, digital soil mapping, aggregation, upscaling, geostatistics, soil carbon assessment

Introduction

It has been estimated that the total global soil carbon (C) pool including wetlands and permafrost (3,250 Pg C) is about five times the biotic pool (650 Pg C) and about four times the atmospheric pool (780 Pg C) (Field *et al*. 2007). Carbon fluxes between soil, biotic and atmospheric pools are dynamic in space and through time and dependent on a multi-factorial system of environmental and anthropogenic drivers. Quantifying C sources, sinks and ecosystem processes that modulate the global C system is critical to identify imbalances and counteract global climate warming. But spatially-explicit assessments of soil C across large landscapes are crude at best. Global soil organic C (SOC) assessment differs widely among soil types, ecosystem types and land uses and has been estimated to vary between 3 to 250 kg/m^2 (after Jacobson *et al*. 2004).

Guo *et al*. (2006) assessed soil C storage across the U.S. using polygon-based legacy data from the U.S. State Soil Geographic (STATSGO) database (currently U.S. General Soil Map) at map scale of 1:250,000. They found that Florida (U.S.) ranks highest in SOC on a per unit area basis among all U.S. states, with 35.3 kg/m^2 up to 2 m over an area of 136,490 km^2. Spatially-explicit point measurements (n: 244) were used to assess SOC in Spodosols in Florida observing concentrations in the range of 10.4 ± 0.8 kg/m^2 from 0 to 1 m, and 18.3 ± 0.8 kg/m^2 from 0 to varying profile depths, of which 9.2 ± 0.6 kg/m^2 were stored in spodic horizons (Stone *et al*. 1993). Conditions in Florida's subtropical landscape are favourable to accumulate large amounts of soil C due to flat topography (0 – 105 m amsl), high water table, extensive freshwater marshes, and high biomass production, which have fostered formation of C-rich soils including Histosols with 11% and Spodosols with 31% soil areal coverage.

The objectives of this study were to (i) synthesize current knowledge on spatially-explicit SOC assessment using different point and polygon soil datasets collected in Florida, U.S. and a large mixed-use watershed nested within Florida, and (ii) compare different digital soil mapping methods (aggregation, geostatistical interpolation, and pedo-transfer functions – PTFs) with different spatial resolutions.

Methods

Datasets

We used two polygon-based soil datasets: STATSGO (scale: 1:250,000, time period: 1994) and Soil Survey Geographic (SSURGO) database (scale: 1:12,000 to 1:31,680, time period: 1961 to 2004) from Soil Data Mart (Natural Resource Conservation Service – NRCS, http:///soildatamart.nrcs.usda.gov). Both Soil Data Mart sets contain soil taxonomic, bulk density (BD), and SOC data associated to soil map units (polygons), which consist of several horizons.

In addition we used horizon-based point observations of SOC from the Florida Soil Characterization Dataset (FSCD, Soil and Water Science Department, University of Florida and NRCS) which entails 1,099 georeferenced BD and SOC observations up to 2 m covering a mapped area of ~140,000 km^2 (time period: 1965 to 1996). The Santa Fe River Watershed (SFRW) (size: 3,580 km^2) was mapped at 141 sites at four fixed depth intervals: 0-30, 30-60, 60-120, and 120-180 cm (time period: 2003 to 2005).

Methodology

All methods produced SOC estimates at the depth from 0 to 100 cm. Method 1 (Florida and SFRW): SOC contents of Soil Data Mart (STATSGO and SSURGO) were calculated by map unit by multiplying the area-weighted average of SOC concentration (in %) by the area-weighted average bulk density (in g/cm^3) of the components within the map unit. Method 2 (Florida): SOC contents were calculated by multiplying the SOC concentration (in %) by the soil bulk density (in g/cm^3) using point FSCD observations. Method 3 (Florida): SOC contents were estimated by block kriging (BK) of ln-transformed SOC observations (FSCD) using a 250-m block size with 5 x 5 averaged estimations within each block. Method 4 (Florida): Average SOC contents by soil order obtained from FSCD observations were applied to STATSGO soil orders (7 in total). Method 5 (SFRW): Ordinary kriging (OK) of ln-transformed SOC observations using a 100-m grid size. Method 6 (SFRW): BK of ln-transformed SOC observations using a 30-m block size with 5 x 5 averaged estimations within each block (Vasques *et al*., 2010). Method 7 (SFRW): Class PTF – Average SOC contents by SSURGO soil series from 139 observations were applied to SSURGO soil series. Method 8 (SFRW): Class PTF – Average SOC contents by soil order/land use (LU) combinations from 139 observations were applied to the respective areas.

Results and Discussion

Spatially-explicit soil organic carbon assessment across a large subtropical region in U.S. (Florida)
The SOC derived by different methods are summarized in Table 1. The mean SOC ranged from 13.85 to 47.80 kg/m^2 and total SOC stocks from 1.99 to 6.82 Pg. STATSGO (Method 1) estimated the upper bound of SOC, whereas FSCD (Method 2) described the lower bound, providing conservative estimates. Total SOC stock in Florida obtained using different data/methods was 4.110 ± 1.01 Pg (mean ± std. error) accounting for approximately 0.13% of soil C on earth assuming that the global pool is 3,250 Pg C (Field *et al.* 2007). According to the soil order class PTF (Method 4), Histosols constitute 11% of Florida soils, but store 53% of the total SOC stock; and Spodosols occupy 31% of Florida soils and store 21% of the SOC. Entisols occupy 24% of the area and store 11% of the total SOC stock. Histosols store the largest amount of SOC with 51.82 ± 23.62 kg/m^2 (mean ± std. dev.) followed by Mollisols (13.98 ± 10.97), Inceptisols (13.20 ± 10.46), Spodosols (8.86 ± 5.81), Alfisols (5.58 ± 4.61), Entisols (4.83 ± 8.58), and Ultisols (4.10 ± 3.56) kg/m^2 (Grunwald 2008).

Currently, Florida's wetlands cover about an area of 15,098 km^2 which has been steadily declining. In the area of the Gulf of Mexico 150,138 ha of wetlands have been lost (1998 to 2004) (Stedman and Dahl 2008) and drainage of the Everglades changed south Florida from a subtropical wetland (~1880) to a human dominated landscape with a strong tourism, retirement, and agricultural economy. As a result, the Greater Everglades ecosystem is half of its original size with current extent of only about 8,250 km^2 which would translate into loss in SOC of about 0.43 Pg C, according to Method 4, in the period of ~1880 to current. Carbon credits and registries promote restoration of wetlands that accumulate large amounts of soil C but need to be cautiously assessed. Considering the formation of a 1-m Histosol soil profile at an accretion rate of 1.1 cm/yr in Florida nutrient-enriched wetlands (Reddy *et al.* 1993) and assuming average methane (CH_4) emissions of 0.85 g/m^2/d (Schipper and Reddy 1994), this would translate into total CH_4 emission of 0.095 Pg CO_2eq. (over a period of 90.9 yrs.) and a total soil C net gain of 0.194 Pg CO_2eq. However, in non-enriched wetlands the soil accretion rate is less with about 0.25 cm/yr (Reddy *et al.* 1993) and contrasts with CH_4 emissions of 0.418 Pg CO_2eq., which would lead to a total soil C net loss of 0.129 PgCO_2 eq. (over a period of 400 yrs.) (Grunwald 2008). These calculations have not yet accounted for the Global Warming Potential factor of 25 for CH_4 (Intergovernmental Panel on Climate Change 2007). Many land use practices – some involving land use changes – have shown to increase SOC and thus received considerable attention for their possible role in climate change mitigation. Fransluebbers (2005) assessed a SOC sequestration rate for the southeastern U.S. at 153.7 Mg CO_2eq/km^2/yr. If 50% of the agricultural area in Florida would be converted from conventional to no-tillage, a total net gain of 1,723,077 Mg CO_2eq/yr could be achieved.

Table 1. Estimates of SOC stocks to 1 m in Florida.

Soil Data	Method	n	Map unit	Min. (kg/m^2)	Max. (kg/m^2)	Mean (kg/m^2)	Std. Dev. (kg/m^2)	Total (Florida) (Pg)	Mean stock (Florida) (kg/m^2)
SSURGO	1	655,155	map unit polygons	0.67	291.77	24.17	39.31	3.52	27.32
STATSGO	1	2,823	map unit polygons	4.01	264.32	58.44	62.67	6.82	47.80
FSCD points	2	1,099	points	0.13	207.98	12.85	23.69	N/A	N/A
FSCD points	3 (BK)	2.28 x 10^6	250-m pixels	2.82	116.19	13.95	12.28	1.99	13.95
FSCD by STATSGO	4	7	soil orders	7.70	144.17	32.84	45.63	4.11	28.83

Spatially-explicit soil organic carbon assessment across the Santa Fe River Watershed in north-central Florida

The SOC derived by different methods are summarized in Table 2. STATSGO overestimated SOC relative to other methods. Overall, best agreement between SOC estimates across the watershed was found in areas of low SOC stock, whereas areas of medium to high SOC (esp. river valleys, wetlands, Histosols, and Spodosols) had higher coefficients of variations (CV) (Methods: 1 and 5-8); thus, contributing to a highly uneven distribution of SOC differences over the watershed (map not shown). The mean CV (Methods: 1 and 5-8) was 42.54% indicating the high variability among different aggregation/upscaling methods to estimate SOC. Average SOC in the watershed was 17.49 ± 6.89 kg/m^2, and total SOC was 61.18 ± 24.08 million tons.

Table 2. Estimates of SOC stocks to 1 m in the Santa Fe River Watershed.

Soil Data	Method	n	Map-unit	Min. (kg/m^2)	Max. (kg/m^2)	Mean (kg/m^2)	Std. Dev. (kg/m^2)	Total (SFRW) (Mg)	Mean stock (SFRW) (kg/m^2)
SSURGO	1	193	map unit polygons	2.93	138.83	21.82	24.42	53,350,771	15.25
STATSGO	1	36	map unit polygons	5.06	173.89	32.09	61.68	105,459,947	30.15
SFRW points	5 (OK)	3.59 x 10^5	100-m pixels	2.62	160.50	10.95	3.67	38,376,698	10.95
SFRW points	6 (BK) [†]	3.98 x 10^6	30-m pixels	3.20	199.37	19.08	6.01	68,389,193	19.08
SFRW by SSURGO	7	174	soil series	2.66	108.04	13.69	18.50	40,515,841	11.58
SFRW by SSURGO/LU	8	24	soil order/LU	5.51	143.52	18.36	28.29	68,220,134	19.50

[†] Vasques *et al.* (2010)

Conclusion

At both extents, Florida and the SFRW, magnitude of differences were found in SOC stocks (means, ranges and absolute values) using different point and polygon soil datasets and aggregation/upscaling methods. Although these subtropical landscapes store huge amounts of SOC, regardless of soil data/methods used, it is difficult to assess which accounting method performs best. Validation of point estimates of SOC (OK) suffer from the effect of different supports between validation soil samples (points) and output pixel sizes, which are assumed to be represented by the point estimate. Block kriging estimates of SOC are difficult to validate since a validation sample would need to represent the variability in SOC within each block. And soil map units are assumed to be internally homogenous and represented by one assigned SOC value, which often does not match variability of SOC across landscapes or validation sample supports. To resolve this dilemma will require joint effort and more research to further explain the variation of SOC and reduce the uncertainty in SOC estimates. Fusing of different soil datasets and methods can help to address these shortcomings as shown in this study.

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