Preparing a soil organic carbon inventory for the United States using soil surveys and site measurements: Why carbon stocks at depth are important

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Abstract
The Fourth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) states that current rates of change in greenhouse gases (GHGs) in the atmosphere have increased substantially from those of the past, and are directly related to increases in air temperature. Strong scientific evidence indicates recent and rapid rate increases of GHGs in the atmosphere can be attributed to human influence. Various IPCC (IPCC, 2007) modeling scenarios project an average 2°C or greater global air temperature rise in the next century, if GHGs emissions are not curtailed. Agricultural practices are responsible for three primary greenhouse gas emissions: carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). The agricultural sector has significant opportunities for offsetting GHG emissions: reduction or avoidance of emissions and through carbon sequestration. This project focuses on carbon sequestration efforts. Soil surveys are combined with site measurements to provide the fundamental national inventory needed for assessing the amount of carbon for sequestration. Soil organic carbon is present in significant quantities throughout the soil profile, therefore it is not sufficient to assess only the surface when measuring carbon. Our methods compare surface and near-surface depths distributions of carbon at 5, 20, and 100 centimeters for the United States.

Key Words
United States, soil organic carbon, soil survey, SSURGO, pedon, site measurement

Introduction
There is strong scientific evidence that human-induced climate change is occurring and that these changes will continue. The Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) states that most observed increases in global average temperatures since the mid-20th century are likely due to observed increases in anthropogenic greenhouse gas concentrations (IPCC, 2007). Scenario modeling indicates that if left unchecked, increasing greenhouse gas concentrations in the atmosphere could result in a global average temperature rise of 2° C or greater (IPCC, 2009) by the end of this century. Increases in global temperatures can result in significant changes in climate including increased duration and intensity of extreme events, impacting food, fiber, and energy security, natural resources and conservation efforts. As the climate changes, those responsible for managing land and water resources will need new information to assist decision-making. This information needs to be accessible nationally, locally and reliably.

Soil organic carbon sequestered by soils is one of the ways in which greenhouse gas emissions can be offset. Baseline data on carbon stocks both at the surface and at depth are critical to understanding how much soil carbon we have and how much is sequestered or could be sequestered both in natural and managed agricultural systems (Follett *et al*., 2009). This paper uses existing soil survey inventories and site-specific information to develop estimates of soil organic carbon stocks at several depths. This inventory demonstrates a first effort to utilize digital detailed soil survey maps with associated estimated attributes and site specific measurements for the United States, whereas earlier efforts focused on limited extents or used generalized soil geographic databases, such as the State Soil Geographic (STATSGO) Database (Bliss *et al*., 1995; Lacelle *et al*., 2000; Bliss *et al*., 2002; Grossman *et al*., 1992).

Methods
Soil organic carbon content values are calculated for three depths (5cm, 20cm and 100cm) using a December 2008 edition of the Soil Survey Geographic (SSURGO) Database for the United States (USDA, 2008). The December 2008 edition of the National SSURGO collection contained 292,179 map units, 842,390 components, and 2,385,878 horizons expressed as 35,470,421 polygon features. Our method is developed as

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a MS SQL Server 2005 script and adapted to the SSURGO 2.1 data structure (USDA 2008) from the method by Bliss *et al*., 1995 and Lacelle *et al*., 2000. Water bodies and miscellaneous areas are excluded from the calculation.

Our initial calculations did not use soil map units that contain null value records providing a conservative soil organic carbon content and mass estimate. Our later calculations use expert rules and soil characterization pedon soil organic carbon content values to supplement SSURGO horizon records that contained a null condition. For calculation of total mass, the geometry of the SSURGO map unit polygon vector features in an Albers Equal Area Conic Projection were used to determine area in square meters. These area estimates are compared with map unit areas reported in the SSURGO database for consistency. These methods are similar to those used by Bliss *et al*., 2009 and Bliss and Mausetter, 2010.

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Results and Discussion

Preliminary results are summarized for individual states and for the nation by land region (Conterminous U.S., Puerto Rico and the U.S. Virgin Islands; Alaska; and Hawaii with selected Pacific Islands) and are still under review at the time of this publication. However, results for the soil organic carbon content and spatial distribution (5cm and 100cm depths) for the state of Iowa, are offered here as an example of the anticipated national result when using the SSURGO database. Table 1 indicates that soil organic carbon stocks within the 100 cm depth can range from 2,570 to 2,582 Tg, with the digital map feature geometry yielding the higher estimate. These values are similar to those computed for the generalized STATSGO database, with a value of 2,743 Tg (Bliss *et al*., 1995). Average 100 cm depth soil organic carbon contents range from 17.6 kg/m^2 when using reported area to 18.1 kg/m^2 when using map feature geometry.

In Table 2, the upper 5 cm soil organic carbon mass is reported as 214 Tg for the state of Iowa. This near surface estimate represents about 8 percent of the soil organic carbon mass present within the upper meter of soil (2,570 Tg) for the same land area. The average soil organic carbon content based on the upper 5cm soil volume is 1.5 kg/m^2. Based on these values, remotely sensed and other near surface (0 to 5cm) assessments of soil organic carbon, could misrepresent the overall soil organic carbon content and mass of the soil profile. Soil profile depths are generally reported to 100 or 150cm depths for the United States.

Table 1. Soil organic carbon (100cm depth) mass estimates for the state of Iowa based on a 12/2008 snapshot of the Soil Survey Geographic Database (SSURGO).

Source Soil Area	Land Area contributing (km^2)	Average SOC Content (kg/m^2)	SOC Mass Tg ($1x10^{12}$ grams)
Albers Geometry	142,562	18.1	2,582
SSURGO Database	145,864	17.6	2,570
Bliss *et al*., 1995 (STATSGO)	143,801	19.1	2,743

Table 2. Comparison of 5cm and 100 cm depth soil organic carbon mass estimates for the state of Iowa based on a 12/2008 snapshot of the Soil Survey Geographic Database (SSURGO). The 5cm depth mass represents about 8% of the 100cm depth mass for soil organic carbon for the state of Iowa.

Depth Range (cm)	Land Area contributing (km^2)	Average SOC Content (kg/m^2)	SOC Mass Tg ($1x10^{12}$ grams)
0 to 5	145,864	1.5	214
0 to 100	145,864	17.6	2,570

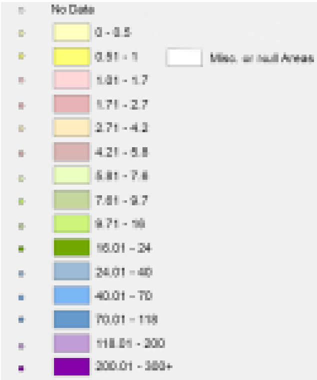

Figure 1. Soil organic carbon content (100cm depth) legend for Figure 2, units are in kg per square meter for both SSURGO grid and pedon site values.

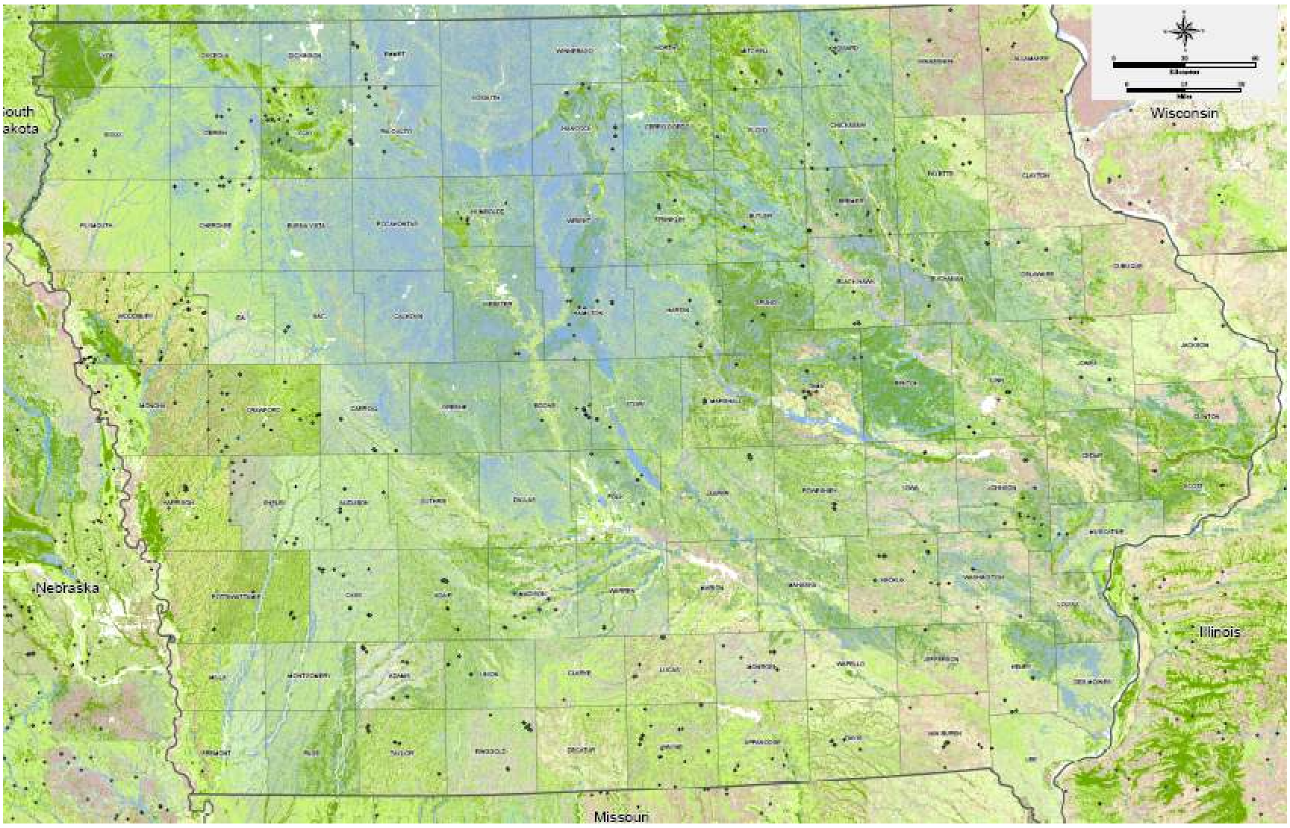

Figure 2. The spatial distribution of soil organic carbon (kg/ m^2) 100 cm depth (SSURGO based) for the State of Iowa with locations of pedon site data.

Figure 1 provides the legend for the 100 cm depth soil organic carbon map of Iowa shown in Figure 2. In Figure 2 the lower value soil organic carbon legend values are shown in pale yellow and tan, moderate values are shown in pale green and blue, and the highest values are shown in pale and deep violet. Water bodies and miscellaneous land areas are shown in white. Locations of pedon sites are also shown in Figure 2.

Conclusion

Soil survey inventories when combined with site measurements can provide the fundamental national inventory needed for assessing baseline soil carbon stocks sequestered. Soil organic carbon is present in significant quantities throughout the soil profile, therefore it is not sufficient to assess only the surface when measuring carbon. Until remotely sensed measurements are calibrated to subsurface information, remotely sensed soil organic carbon inventories should be considered only minimum estimates.

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