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Scale-dependent variability of soil organic carbon coupled to land use and land cover

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ABSTRACT

Understanding the field-scale spatial variability of soil organic carbon (SOC) is critical to assess its spatial distribution at very fine scale (several meters) which is valuable for precision agriculture and natural resource management. The aim of this study was to investigate the field-scale spatial variability of SOC under five prevalent land use and land cover (LULC) types in Florida, U.S. with a uniform sampling scheme. Five scales, 2, 7, 22, 67 and > 200 m, were targeted and 108 soil samples at 0–20 cm depth were collected and analyzed for SOC and bulk densities within each LULC type in 2012. Results indicate that SOC variability was scale dependent. Hardwood Hammock and Forest and Improved Pasture demonstrated large variation at both coarse scale (67 and > 200 m) and very fine scale (2 m). Sandhill, Pineland and Dry Prairie were dominated by variation at very fine scales (2 and 7 m). All five sites showed large variability at very fine scales, indicating the close coupling of SOC stock variation to structure and composition of vegetation. This study also identified that log-transformed SOC showed variance-invariant behavior, which had an approximately constant overall variance (sill) of 0.067 ± 0.012 (log (kg m^{-2}))^2 at field scale (~500 m) irrespective of LULC. These findings serve to explain field-scale variability of SOC relevant for precision agriculture and land management, but also facilitate better understanding of the scale-dependent fine-scale variability of SOC across larger soilscapes.

1. Introduction

In the context of sustainable agriculture and global climate change there has been great interest in soil organic carbon (SOC) (Batjes and Sombroek, 1997; Bellamy et al., 2005; Franzluebbers, 2005; Spargo et al., 2008). Globally, great efforts have been dedicated to quantifying the spatial distribution and achieving accurate assessments of SOC (Grunwald, 2009; Minasny et al., 2013). However, the current soil spatial data around the globe are at rather coarse scale (Grunwald et al., 2011). For example, in the U. S. the major two soil databases providing readily available soil data are State Soil Geographic Database (STATSGO2) and Soil Survey Geographic Database (SSURGO via Soil Data Mart) at scale of 1: 250,000 and 1:24,000, respectively. These soil databases cannot reflect SOC variation at field scale (i.e., within a few hundred meters) and provide little spatial information for precision agriculture and land management.

There have been field-scale studies of SOC variability, however they are difficult to compare because of differences in sampling design, protocols, density of observations, sample support, carbon (C) measurement techniques, soil depth, and other factors. Even though these studies were conducted in different climatic zones, land use and land cover (LULC), soil classes, topography, and intensity of human interferences, the maximum spatial autocorrelation ranges rarely exceeded 500 m (Cambardella et al., 1994; Cerri et al., 2004; McBratney and Pringle, 1999; Rossi et al., 2009; Terra et al., 2004; Trangmar et al., 1987). These studies provide knowledge about the field-scale variability of SOC under specific environmental and geographic conditions. However, they lack the ability to generalize because differences in the field-scale variation of SOC may be due to methodology, SOC variation, or scale-dependent relationships between SOC and other prominent environmental conditions, such as topography, climate, or net ecosystem productivity (Corstanje et al., 2007; Vasques et al., 2012). Florida soils hold a large amount of C and have great potential to accumulate more carbon. According to the estimates of SOC based on the State Soil Geographic database (STATSGO) by Vasques et al. (2010), Florida has the highest SOC stock value per

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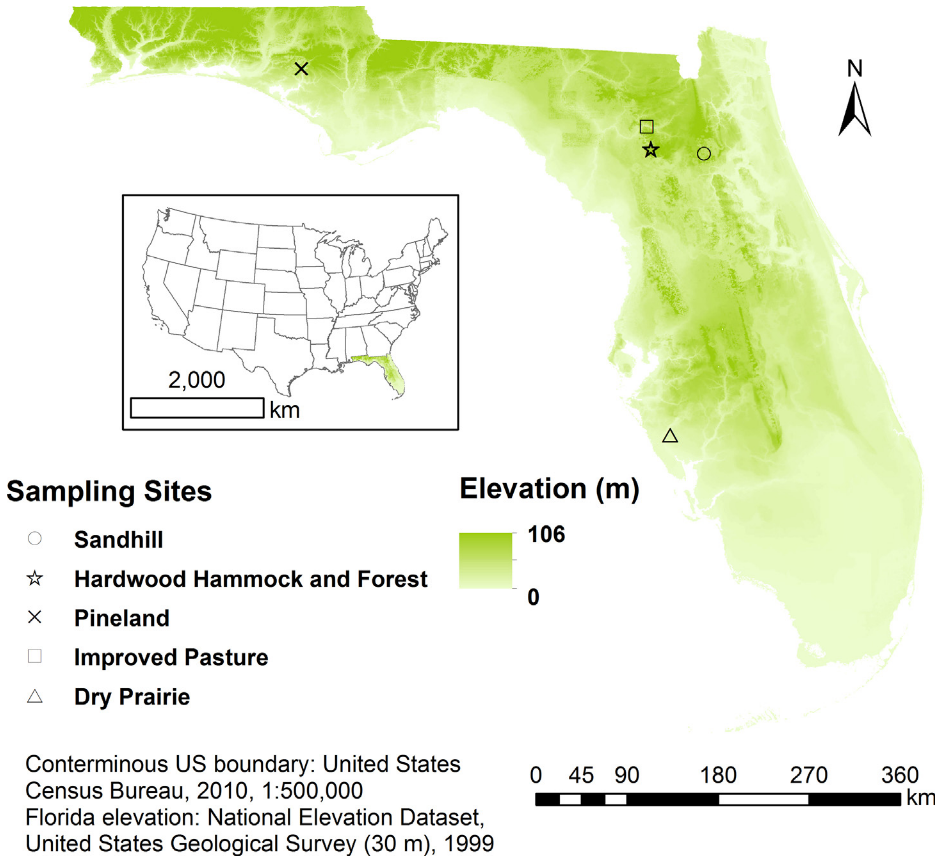

Fig. 1. Sampling sites under five land use and land cover classes and soil orders in Florida.

unit area among the conterminous U.S. states with minimum, median, and maximum values of 12.4, 35.3, and 64.0 kg m^{-2}, respectively. In addition, Florida enjoys a wide variety of LULC classes unique to the Southeastern U.S. and SOC stocks can vary dramatically among ecosystems (Vasques et al., 2012; Xiong et al., 2014). However, little effort has been dedicated to the understanding of fine-scale spatial variability of SOC within and across different LULC types in this region.

Various sampling designs to investigate scale dependent variation of SOC that minimizes sampling effort have been suggested. Youden and Mehlich (1937) introduced a spatially nested sampling design to study soil spatial variation over multiple magnitudes of scales cost-effectively compared with systematic or random sampling techniques. Webster et al. (2006) formulated the theory of this technique. They successfully applied both balanced and unbalanced spatial nested sampling schemes to study various soil properties and reported the unbalanced design had comparable performance to the balanced one with much fewer samples and better distribution of degrees of freedom across scales. Lark (2011) then explored the scope for optimization of the unbalanced spatially nested design using simulated annealing and claimed that the optimization can theoretically yield better estimation of variance components (i.e., smaller variance of estimation) given a fixed number of samples and scales.

The major objective of this study was to investigate the field-scale variability of SOC under five common LULC classes in Florida with a uniform spatially nested sampling scheme. The specific objectives were to (i) investigate and compare the spatial structures of SOC in five LULC classes at field-scale (< 500 m); (ii) identify the scale-dependent behavior and the controlling factors of SOC variation, and (iii) obtain an average semivariogram to capture the general characteristics of the SOC spatial variability at field scale.

2. Materials and methods

2.1. Description of study areas

The study areas are located in Florida, a state in Southeastern U. S., with latitudes from 24°27′ N to 31°00′ N and longitudes from 80°02′ W to 87°38′ W. The climate of Northern and Central Florida is humid, subtropical and Southern Florida has tropical climate. The mean annual precipitation of Florida is 1373 mm and the mean annual temperature is 22.3 °C (National Climatic Data Center, 2008). Overall, soils in Florida are sandy in texture. Dominant soil orders of Florida are: Spodosols (Podzols in World Reference Base for Soil Resources, 29%), Entisols (Fluvisol, 20%), Ultisols (Acrisol, 17%), Alfisols (Luvisols, 12%) and Histosols (Histosols, 10%) as shown in Fig. 1 (Natural Resources Conservation Service, 2009). Florida's topography is muted with gentle slopes varying from 0 to 5% in almost the whole state (United States Geological Survey, 1999).

To investigate the field-scale variation of SOC under different LULC, five of the most prevalent and contrasting LULC classes in Florida were selected for sampling, namely Pineland (accounting

[1] The definition of Dry Prairie adopted in this study is a large native grass and shrubland occurring on very flat terrain interspersed with scattered cypress domes and strands, bayheads, isolated freshwater marshes, and hardwood hammocks, according to Florida Fish and Wildlife Conservation Commission (2003).