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Spatial pattern and uncertainty of soil organic carbon and implications for sampling design

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Introduction Woody encroachment has occurred in many arid and semi-arid ecosystems all over the world (Archer 1995). Invasion of woody plants into grassland savanna has significant impacts on soil carbon storage and its spatial heterogeneity (Boutton et al. 1998). We have limited understanding on the pattern of special heterogeneity and uncertainty of soil carbon and its relationship to the spatial pattern of woody vegetation in savanna landscapes. This understanding is essential for effective assessment and monitoring of soil carbon in savanna landscapes. The goal of this study was to develop an understanding of the spatial pattern and uncertainty of soil organic carbon (SOC) and how they influence the effectiveness of SOC estimation in subtropical savanna landscapes. The specific objectives were to: (1) quantify the spatial uncertainty of SOC; (2) evaluate the performance of different point sampling designs in estimating SOC storage; and (3) develop effective sampling strategies based on the spatial pattern and uncertainty of SOC.

Materials and methods This study was conducted at the Texas AgriLife Research La Copita Research Area (27°40′N, 98°12′W) in south Texas. The upland portions of the landscape are subtropical savanna parklands with discrete woody patches scattered in a continuous C4 grassland matrix. Woody patches with honey mesquite canopy and understory shrubs were classified as smaller clusters (1-100 m^2) and larger groves (>100 m^2). A 160m×100m plot was established on the upland landscape with 10m×10m grid cells. Soil samples were collected at 2 random points in each grid cell. Additional subplots on 3 groves, 5 clusters and 3 grassland areas were also sampled with higher intensities. Soil samples were processed and SOC concentration was measured by combustion/gas chromatography using a Carlo Erba EA-1108 elemental analyzer. Aerial photo imagery was classified into either woody or non-woody classes and the woody patches were identified as clusters or groves based on their sizes. Kriging and conditional stochastic simulation approaches (Goovaerts 2001) were used to qualify the pattern of spatial uncertainty in SOC estimations. Based on the understanding of the pattern of spatial uncertainty, alternative sampling designs were developed and examined for their effectiveness measured as the estimation error as a function of sample density.

Results Average SOC content was significantly different between vegetation types and decreased from groves to clusters and grasslands (1832, 1500, and 1282 g C m^{-2}). Spatial distribution of SOC based on kriging indicated that it was closely related to the spatial distribution of woody vegetation density. Results of the conditional stochastic simulation showed significantly greater levels of uncertainty of SOC estimations in groves than in clusters and grassland. Consistent differences in estimation error were found among the complete random sampling, stratified random sampling with even density, and stratified random sampling with uneven density (based on level of uncertainty). Stratified random sampling with unequal densities had the lowest estimation error while complete random sampling had the highest at all sampling density. Estimation errors of all three designs started to level off when sampling density was higher than 100 samples per hectare. Results of the complete random sampling experiments with simulated landscapes showed that estimation errors increased with increasing woody vegetation cover for all sampling densities and both percentage of woody cover and relative abundance of clusters vs. groves influence the estimation errors. Results of experiments also showed that structured sampling would be most effective for clusters given the strong patterning from center to edge of the clusters.

Conclusions The invasion of woody vegetation into grassland, deserts and savannas has profound impacts on both the magnitude and spatial heterogeneity of SOC content. In order to evaluate effects of woody invasion on soil carbon at large spatial scales, understanding of spatial uncertainty of SOC is essential in designing suitable sampling regimes to estimate SOC storage. Our results showed that SOC had higher spatial uncertainty as well as higher concentrations in woody patches than in the grassland. High uncertainty of SOC in woody patches was likely caused by complex canopy structure, root distribution and animal disturbance. Assessment of alternative sampling designs demonstrated the effect of spatial uncertainty on estimation accuracy of SOC storage and helped generating effective sampling strategies to improve SOC estimation accuracy. This understanding of spatial uncertainty of SOC can also enable new approaches to estimate and monitor soil carbon storage over large landscapes based on remote sensing.

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