Research Application Summary

Spatial variation of soil organic carbon under the linear simultaneous agroforestry system

Balaba Tumwebaze, S.[1], Bevilacqua, E.[2], Russell Briggs[2] & Volk, T.[2]
[1]School of Forestry, Environmental and Geographical Sciences, Makerere University, P. O. Box 7062 Kampala, Uganda
[2] State University of New York, College of Environmental Science and Forestry, Department of Forestry and Natural Resources Management, 1 Forestry Drive 320 Bray Hall, Syracuse NY 13210. USA
Corresponding author: balaba2@yahoo.com; tumwebaze@forest.mak.ac.ug

Abstract

Most research on spatial variability of soil organic carbon (SOC) has been conducted in forest and grassland soils, but no research has been conducted on agroforestry soils. Knowledge about the variability of SOC can assist in generating effective sampling designs and can help to scale-up carbon inventories. The aim of this study was to investigate the spatial variation of SOC concentrations in linear simultaneous agroforestry systems and recommend a suitable sampling design. The study was conducted at Kifu National Forestry Resources Research Institute (NaFORRI) in Mukono district, Central Uganda. The study was conducted within an existing experiment, established in 1995 as a randomised complete block design with a multi-factor factorial treatment structure. Soil samples were collected at three depths; 0-25 cm, 25-50 cm, and 50-100 cm, twice; before clearing the site and planting the maize crop and after harvesting. Geostatistical tools were used to describe and predict spatial variation using semi-variograms, and to conduct spatial interpolation. Results indicate that spatial dependencies among neighbouring locations exist at all soil depths. However, results indicate a short distance of spatial continuity of SOC, varying from 3.4 to 13.8 m. Knowledge of spatial arrangement can be used to form strata and hence stratified random sampling design is recommended to be used in future data collection procedures. In order to improve the precision of the estimated SOC, a distance of less than 6.9 m between sampling points would be appropriate to capture the spatial autocorrelation in the linear simultaneous or similar agroforestry system.

Key words: Agroforestry, carbon inventories, semi-variograms, soil organic carbon, spatial variation

Résumé

La plupart de recherches sur la variabilité spatiale du carbone organique du sol (COS) ont été menées dans le sol des forêts et celui des prairies, mais aucune recherche n’a été menée sur les sols de l’agroforesterie. La connaissance de la variabilité du COS peut aider à générer des plans efficaces d’échantillonnage et aider à échelonner les stocks de carbone. Le but de cette étude est d’examiner la variation spatiale des concentrations en COS dans les systèmes agroforestiers simultanés linéaires et de recommander un plan d’échantillonnage approprié. L’étude a été menée à l’Institut National de Recherche en Ressources Forestières de Kifu (NaFORRI) dans le district de Mukono, en Ouganda central. L’étude a été menée dans une expérience existante, créée en 1995 comme un dispositif en blocs aléatoires complets avec une structure multi-factorielle de traitement factoriel. Des échantillons de sol ont été prélevés à trois profondeurs; 0-25 cm, 25-50 cm et 50-100 cm, deux fois : avant de nettoyer le site et de planter le maïs, et après la récolte. Des outils géostatistiques ont été utilisés pour décrire et prévoir la variation spatiale à l’aide de semi-variogrammes, et de procéder à une interpolation spatiale. Les résultats indiquent que les dépendances spatiales entre les emplacements voisins existent à toutes les profondeurs du sol. Cependant, les résultats indiquent une courte distance de la continuité spatiale du COS, variant de 3,4 à 13,8 m. La connaissance de l’arrangement spatial peut être utilisée pour former les strates et ainsi, le plan d’échantillonnage aléatoire stratifié est recommandé pour être utilisé dans les futures procédures de collecte des données. Afin d’améliorer la précision du COS estimé, une distance de moins de 6,9 †m entre les points de prélèvement serait appropriée pour reproduire l’auto-corrélation spatiale dans le système agroforestier simultané linéaire ou dans le système analogue.

Mots clés: Agroforesterie, stocks de carbone, semi-variogrammes, carbone organique du sol, variation spatiale

Background and Literature

Soil organic carbon (SOC) levels are known to be influenced by a large number of factors, many of which are mutually interactive. These include: parent material, soil texture, climate, soil pH, topography, drainage, vegetation, land use and management. Manipulation of some of these factors, especially management-related ones, may be used to increase carbon (C) sequestration in soils and thus mitigate national climate change commitments (Smith *et al*., 2000). Statistical and geostatistical procedures have been used to study the relationships between SOC and these factors, and to quantify spatial distribution patterns and changes in SOC (Frogbrook and Oliver, 2001). Soil characteristics tend to be correlated over space, both vertically and horizontally, and when such heterogeneity and interactions occur, it is necessary to describe spatial structures and scale (Bartoli *et al*., 1995).

Understanding the distribution of soil properties in the field is important in refining agricultural management practices (McBratney and Pringle, 1999) while minimising environmental damage. Soil property variation within a field often has been described by classical statistical methods assuming a random distribution (Goovaerts, 1999; Webster, 2001; Conant and Paustian, 2002). In many instances, spatial variation is not random and tends to increase as distances increases between points in space. Spatial dependence has been observed for a wide range of soil physical and biological properties (Goovaerts, 1998), but typically the size of the studied area is relatively small, commonly ranging from 1 m^2 to 1 ha. Geostatistical techniques that provide the means to characterise and quantify spatial variation have been used to process this information for rational interpolation, and to estimate the variance of interpolated values (Isaaks and Srivastava, 1989; Webster and Oliver, 2001).

There is a need to obtain reliable information on the variation of soil properties within fields so that management decisions can be made effectively. However, a major difficulty in the progress of site–specific management at present is to obtain enough information about soil properties to produce reliable estimates for mapping. Kerry and Oliver (2007) noted that a common approach to agricultural sampling is one sample per hectare, which even for a large field of 50 ha would not provide an adequate sample size to compute an accurate variogram. More still, this method does not account for the spatial scale of variation present in the study site. Therefore, a number of sampling issues still need to be addressed, such as suitable sample size, how the sampling points should be distributed over the site of interest and how different degrees of spatial variation affect the data requirements (Kerry and Oliver, 2007).

Most research on spatial variability of soil organic carbon (SOC) has been conducted in forest (Oliver *et al*., 2004; Schoning *et al*., 2006) and grassland soils (Conant and Paustian, 2002; McGrath and Zhang, 2003; Zhang and McGrath, 2004; Don *et al*., 2007) but no research has been conducted on agroforestry soils. Knowledge about the variability of SOC can assist in generating effective sampling designs and can help to scale-up carbon inventories (Don *et al*., 2007). Therefore, the aim of this study was to investigate the spatial variation of SOC concentrations in linear simultaneous agroforestry systems and recommend a suitable sampling design.

Study Description

The study was conducted at Kifu National Forestry Resources Research Institute (NaFORRI) in Mukono district in Central Uganda. The field work was conducted within an existing experiment, established in 1995 as a randomised complete block design with a multi-factor factorial treatment structure(Okorio, 2000; Wajja-Musukwe, 2003). Soil samples were collected at three depths; 0-25 cm, 25-50 cm, and 50-100 cm, twice; before clearing the site and planting the maize crop and after harvesting. The vegetation is characterised by elephant grass (*Pennisetum purpureum*) and remnants of high tropical forest and eucalyptus woodlots (Okorio, 2000). Swamps are covered by papyrus reeds (*Cypresus papyrus*) and sedges are found in several valley bottoms. Kifu is set in the crystalline basement characterised by metamorphosed granites and soils originating from quaternary alluvial and lacustrine deposits (Water Department, 1996). The FAO/UNESCO soil map classifies the soils as mainly Ferralsols, with Gleysols in the swamps and a small area of Intosols. The soils are slightly acidic sandy loams with bulk densities in the range of 1.5 to 1.7 Mg m^{-3} (Okorio, 2000).

Research Application

Geostatistics procedures require a variable to have a continuous surface. The data from linear simultaneous agroforestry system have a step function due to the species differences. To obtain a continuous surface for linear simultaneous agroforestry system data, the species effect was removed. In order to remove the confounding effect of species, the soil organic carbon data used in the analysis were adjusted by obtaining residuals from complete randomised design and adding the grand mean to the residuals to obtain a new variable of soil organic carbon without the species effect. Spatial variability of SOC was analysed by use of geostatistical tools, namely semi-variogram, correlogram, madogram and kriging (Schöning *et al.*, 2006). SOC was adjusted for species effect and analysed by simple random sampling (SRS), stratified random sampling (STS), trend analysis (TRE), and kriging (KMRE). Mean and total SOC with the corresponding variance and standard error were computed for each estimator. The magnitude of the standard error and variance of the mean SOC and total SOC were used to assess the precision of these procedures.

The variograms indicate that the semi-variance is increasing with increasing separation distance and then stabilises. These results demonstrate that SOC is spatially auto-correlated. Variogram analysis indicate that the range at which SOC is not spatially autocorrelated before planting maize is 72.6 m, 3.4 m and 24.8 m for soil depths of 0-25 cm, 25-50 cm and 50-100 cm, respectively. This indicates that SOC is spatially auto-correlated at wide distances for soil depth 0-25 cm and 50-100 cm as compared to 25-50 cm. After planting maize crop, SOC was still spatially auto-correlated, however the range at which correlation existed changed. The range for SOC changed from 13.8 m to 9.8 m to 5.3 m for soil depths 0-25 cm, 25-50 cm and 50-100 cm, respectively This result indicates that the range at which SOC is spatially auto-correlated reduces with depth after planting the maize crop.

Block kriging was used to predict SOC at unsampled locations, and 2D and 3D kriging maps of the predicted SOC were constructed for the whole study area. Figure 1 shows that high SOC is found in the plots in the south west and North West for soil depth 0-25 cm. The values of SOC in these plots range from 23.3 to 24.4 g C kg^{-1}. The plots found in the north east and south east had lower SOC ranging from 19.1 to 21.1 g C kg^{-1}. There is a north-east and south-west diagonal band of SOC (Fig. 1). Figure1 further indicates that lower values of SOC (16.6-20.1 g C kg^{-1}) were found in plots in the north-east and north-west while higher values of SOC (20.1-22.4 g C kg^{-1}) were found in south-west and south-east at soil depth 25-50 cm. At soil depth 50-100 cm, low values of SOC ranging from 13.8-16.5 g C kg^{-1} covered the whole study site with spots of high SOC and low SOC values scattered throughout the study site (Fig. 1).

After planting maize crop, the north-east and south-west diagonal trend of SOC still existed, high values of SOC (22.9-26.0 g C kg^{-1}) were found in the plots in the north west (Figure 2), while low values of SOC (18.2-21.3 g C kg^{-1}) were found in the north east plots. The remainder of the study site at 0-25 cm soil depth had a mixture of high and low SOC values. Figure 2 shows that plots in the south-west had high values of SOC (19.5-21.5 g C kg^{-1}) and low SOC values were found in the north-west and north-east at soil depth 25-50 cm. The rest of the area had a mixture of low and high values of SOC. For 50-100 cm soil depth (Fig. 2), much of the area had SOC ranging from 14.9-16.3 g C kg^{-1} and some plots in the north-east had

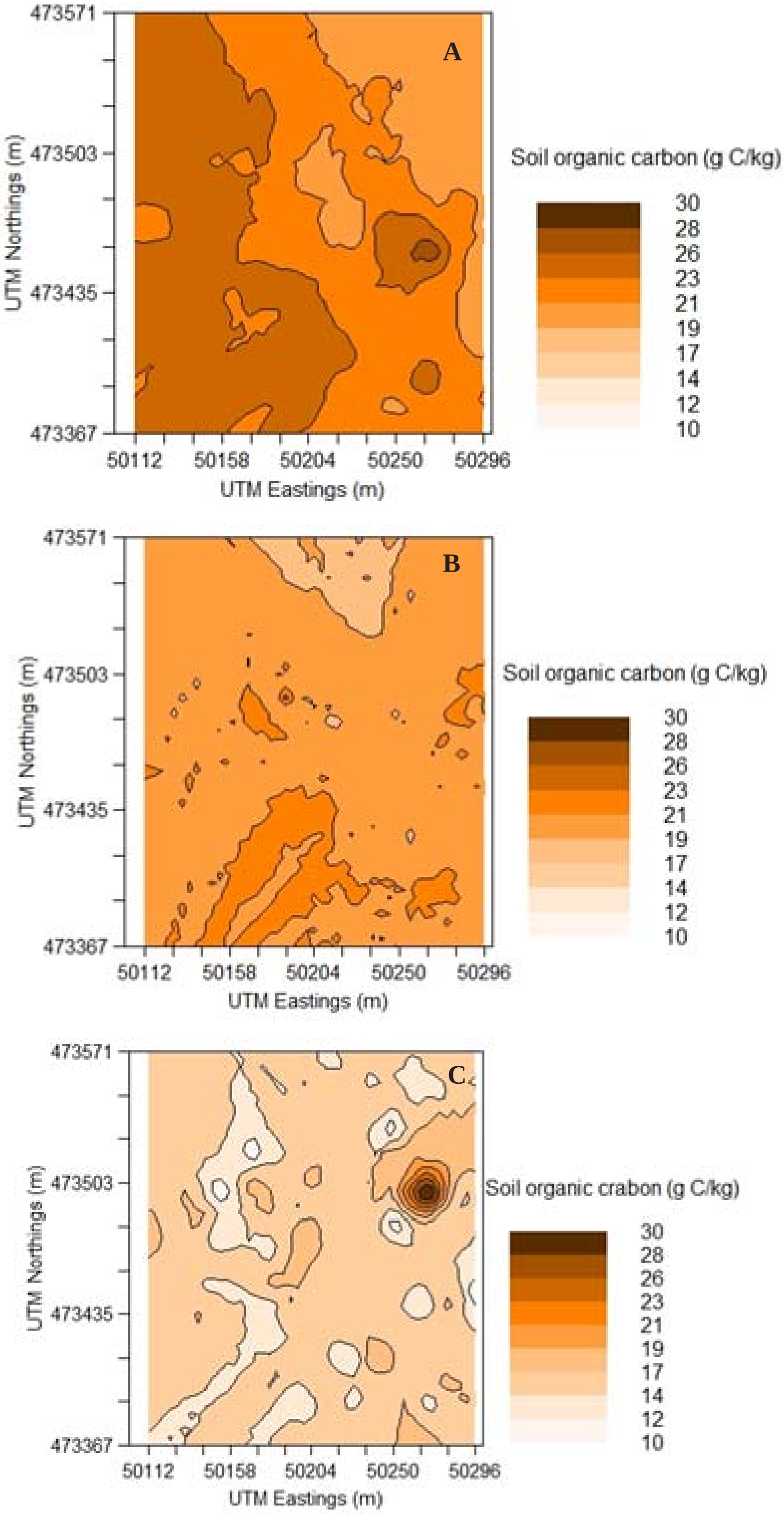

Figure 1. Kriging map of soil organic carbon (before planting maize) at soil depths of (a) 0-25 cm, (b) 25-50 cm, and (c) 50-100 cm.

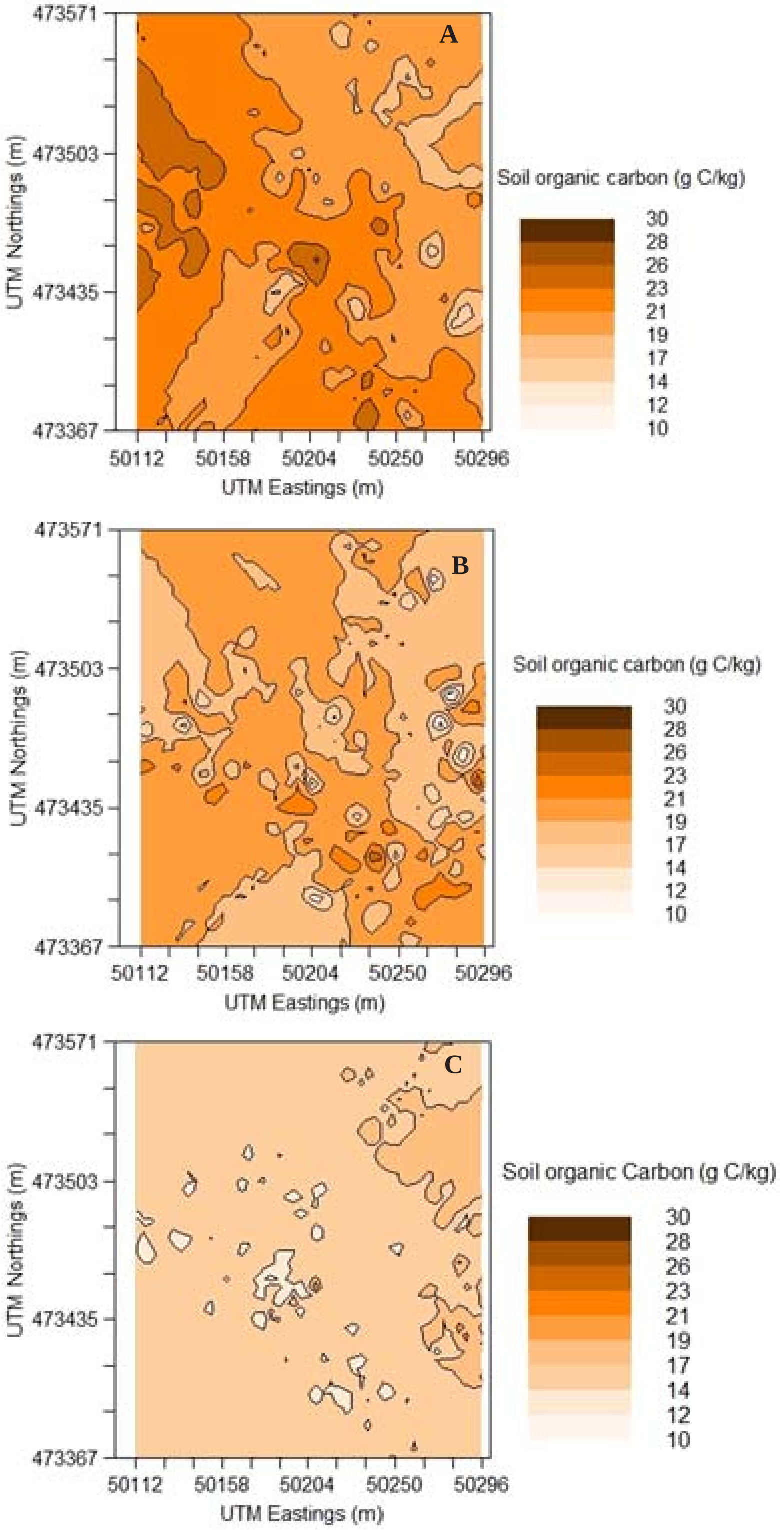

Figure 2. Kriging of soil organic carbon after harvesting maize at soil depths of (a) 0-25 cm, (b) 25-50 cm, and (c) 50-100 cm.

SOC values of 16-3 - 17.7 g C kg^{-1}, with spots of higher SOC values.

The estimate of mean SOC is consistent among all the methods (simple random sampling (SRS), stratified random sampling (STS), trend analysis regression estimator (TRE) and kriging like model-based regression estimator (KMRE). Accounting for spatial variation by blocking (STS) improves the precision of the mean SOC estimate by 12.7% for 0-25 cm soil depth compared to SRS.

Conclusion

SOC exhibits spatial dependencies among the neighboring locations of the study site for each depth and both data sets (before and after planting maize). There was no anisotropic pattern in SOC indicating no obvious differences in the spatial structure in all direction. Stratified random sampling was chosen as a suitable method for collecting data in future studies in linear simultaneous or similar agroforestry system, since the method incorporates the existing spatial arrangement in the design.

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