Landscape-scale sampling of forest-derived carbon in cultivated systems of East Africa

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Abstract
Loss of natural ecosystems and the increase of annual cropping systems are inextricably linked to ecosystem function and food security. Understanding how land-use change contributes to functional soil properties such as soil organic matter cycling will help in the design of agricultural systems in order to enhance the soil ecosystem. Three Millennium Village (MV) sites (Sauri, Kenya; Ruhiira, Uganda; and Mbola, Tanzania) were chosen to develop soil organic carbon reference values at a landscape scale. Mbola site was further selected to construct a chronosequence to calculate organic matter turnover rates on two different soil types prevalent across the landscape. These three sites represent distinct forest types and are at various stages along the restoration-degradation pathway. The Land Degradation Surveillance Framework (LDSF) developed by Markus Walsh and Tor Vagen was used to sample the landscape and is a stratified random sampling design that uses a nested spatial hierarchy. Soil organic carbon (SOC) and stable carbon isotopes were measured on 171 composite soil samples from 0-20 cm and 20-50 cm depths. Paired sampling of forested and cultivated sites at the Mbola village was conducted and soil pits were excavated to classify and describe soil. Multilevel models were used to analyse variance within the hierarchy and to model parameters at different spatial scales. SOC, sand content, carbon isotope signatures varied between the three sites. SOC reference values and SOM turnover rates will be calculated and presented.

Key Words
Stable carbon isotopes, SOC, SOM.

Introduction
Loss of natural ecosystems, diminishing ecosystem function, and the prevalence of non-replenishing cropping systems are inextricably linked to food security. It is estimated that while 70% of Africa's population live in rural areas and depend almost solely on agriculture, over half of Africa's land is unsuitable for agriculture (Swift and Shepherd 2007). Degradation of soil and water resources is suggested to inhibit the needed increase in food production in sub-Saharan Africa (Verchot *et al.* 2005). Understanding how land-use change contributes to functional soil properties such as soil organic matter cycling may help in the design of agricultural systems in order to enhance the soil ecosystem. Soil provides multiple ecosystem services (i.e. medium for plant and agricultural production, filtering of toxins and pollutants and regulating the hydrologic cycle) (Millennium Ecosystem Assessment 2005). Specifically, soil organic matter (SOM) is described as one for the three core soil properties contributing to soil function (Palm *et al.* 2007). Its depletion or degradation can have serious impacts on aboveground productivity. Yet, the impacts of land-use change on SOM cycling in sub-Saharan Africa are still understudied. A landscape-scale understanding of SOM dynamics, beyond carbon stock calculations, is lacking, particularly in areas where smallholder farmers critically need this information most. Creating regional SOC reference values for semi-natural and cultivated sites across a landscape will help guide management recommendations and provide useful information about basic ecosystem function for a converted landscape. In addition, calculating soil organic matter turnover rates will improve our understanding of effects of forest conversion on the carbon cycle.

Soil Organic Matter Dynamics
Stable carbon isotope signatures in the soil allude to vegetation composition because photosynthetic pathways of plants discriminate against the heavier carbon isotope differently. Most plants and trees, use the C3 (Calvin cycle) photosynthetic pathway and have a more negative $\delta^{13}C$ value compared to maize and other cereal crops and grasses which utilize the C4 (Hatch-Slack) pathway. Stable carbon isotopes have been used to determine the SOM turnover rates at local scales (Balesdent and Mariotti 1996, Bernoux *et al.* 1998), identify vegetative sources of organic matter to the soil (Roscoe *et al.* 2001, Krull *et al.* 2007), and address the impact of land conversion on soil condition (Vagen *et al.* 2006, Awiti *et al.* 2008, Schulp and Veldkamp 2008). This project will build on these studies by comparing three different forest types and utilizing a

spatially balanced sampling design to understand landscape-scale SOM dynamics.

Methods

Three Millennium Village (MV) sites (Sauri, Kenya; Ruhiira, Uganda; and Mbola, Tanzania) were sampled because they represent three distinct forest types and have varying degrees of land-use change (Table One). The Land Degradation Surveillance Framework (LDSF) developed by Markus Walsh and Tor Vagen was used to collect soil samples across the study sites. LDSF is a stratified random sampling design using a nested spatial hierarchy (Figure 1). Composite soil samples were taken from four subplots within each plot from 0-20-cm and 20-50-cm depths. Soil samples were air dried and sieved to 2 mm. One hundred and seventy-one soil samples were analysed for stable carbon isotopes and soil organic carbon with a stable-isotope-ratio mass spectrometer on whole soil samples at Iso-analytical Laboratories in the UK (http://www.iso-analytical.co.uk/). Isotope results are reported in standard delta notation relative to a Pee-Dee Belemnite (PDB) standard. Twenty percent of the samples received a duplicate analysis for quality control.

Table One. Millennium Village Site Descriptions.

MV Site	Forest Type	Where on the degradation/restoration pathway
Mbola, Tanzania	Miombo Woodland	Land conversion still occurring
Ruhiira, Uganda	Sub-humid highland forest	Deforested
Sauri, Kenya	Humid/sub-humid forest	Was deforested, tree plantings are occurring

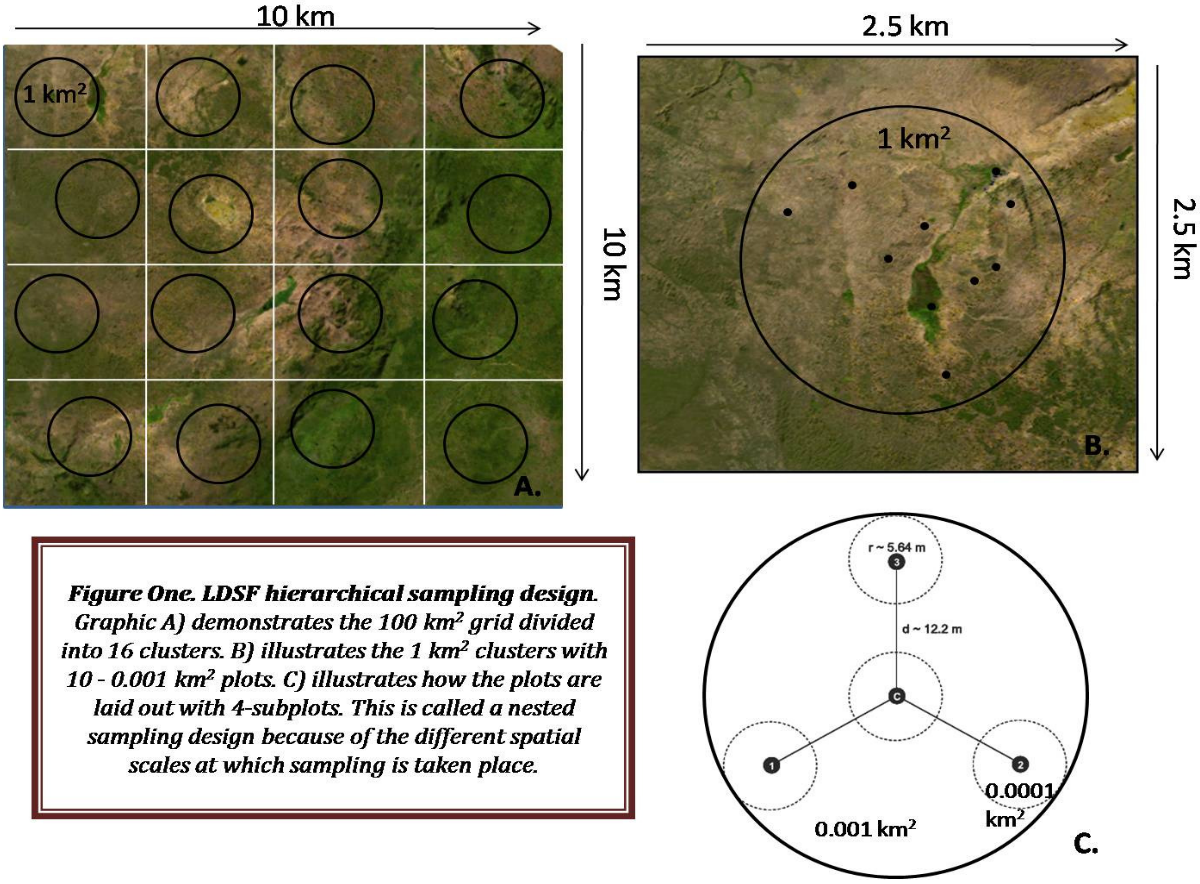

Figure One. LDSF hierarchical sampling design. Graphic A) demonstrates the 100 km² grid divided into 16 clusters. B) illustrates the 1 km² clusters with 10 - 0.001 km² plots. C) illustrates how the plots are laid out with 4-subplots. This is called a nested sampling design because of the different spatial scales at which sampling is taken place.

Figure 1. Land Degradation Surveillance Framework sampling design.

Chronosequence Soil sampling

To compliment this sampling strategy, eight new paired sites, forest and cultivated sites with known time since conversion, were selected and sampled within LDSF framework at the Mbola, Tanzania Millennium

Village to calculate SOM turnover rates for the Miombo Woodland region. Farmer interviews provided information on land-use history including time since conversion for the cultivated sites. Soil pits were excavated and soils at each paired site were classified using Soil Taxonomy and World Reference Base to ensure morphological homogeneity within the paired sites. Undisturbed soil cores were taken to determine bulk density at three depths 0-20, 20-50, and 50-100 cm.

Calculations and Statistical Modelling

Soil organic carbon reference values will be calculated controlling for sand content for each of the sites and presented for the landscape. Soil organic matter turnover rates will be calculated along a chronosequence of land use using stable carbon isotope values and time since conversion using linear mixed effect models performed in the statistical package R. These data will allow us to compute the percent of tree-derived carbon in the soil along a chronosequence of time since conversion.

Preliminary Results

Total soil organic carbon contents and sand content were clustered for the three villages (Figure 2). Mbola, TZ site had the highest sand content and lowest SOC values. Delta carbon 13 values for top and sub soil at each of the village sites indicate the prevalence of mixed C3-C4 systems.

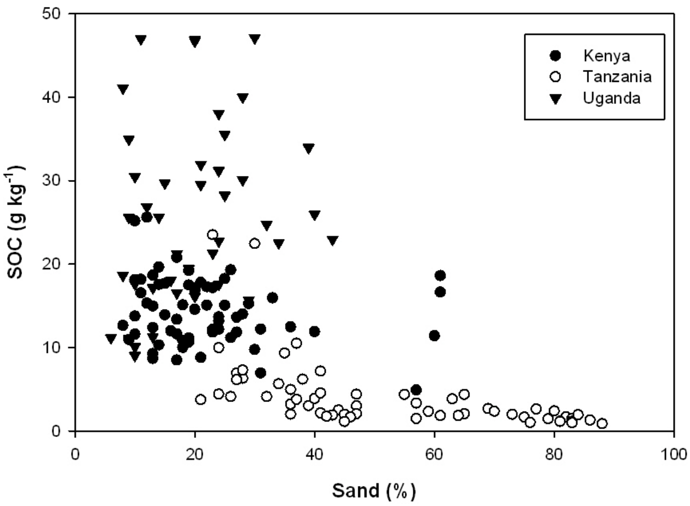

Figure 2. SOC vs sand for top and subsoil samples at the three Millennium Village Sites.

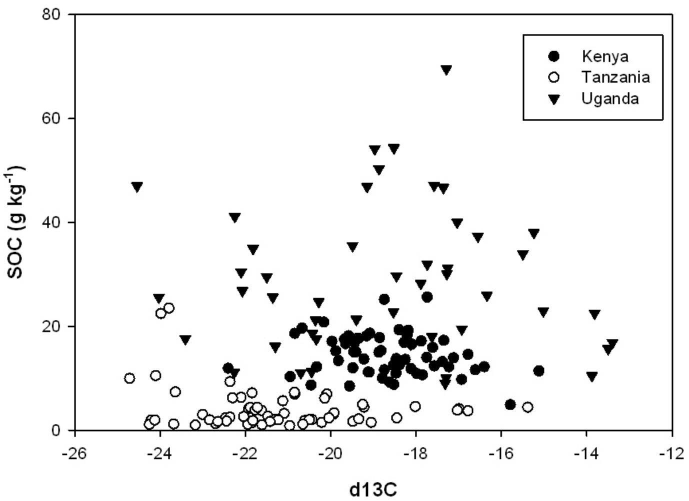

Figure 3. SOC vs δ^{13}C values for top and subsoil samples at the three Millennium Village Sites.

References

Awiti A, Walsh M, Shepherd K, Kinyamario J (2008) Soil condition classification using infrared spectroscopy: A proposition for assessment of soil condition along a tropical forest-cropland chronosequence. *Geoderma* **143,** 73-84.

Balesdent J, Mariotti A (1996) Measurement of soil organic matter turnover using C-13 natural abundance. Pages 83-111 *in* T. W. Boutton and S. Yamasaki, editors. Mass Spectrometry of Soils. Marcel-Dekker, New York.

Bernoux M, Cerri C, Neill C, de Moraes JFL (1998) The use of stable carbon isotopes for estimating soil organic matter turnover rates. *Geoderma* **82,** 43-58.

Krull E, Bray S, Harms B, Baxter N, Bol R, Farquhar G (2007) Development of a stable isotope index to assess decadal-scale vegetation change and application to woodlands of the Burdekin catchment, Australia. *Global Change Biology* **13,** 1455-1468.

Millennium Ecosystem Assessment (2005) Ecosystem and Human Well-being Synthesis. Island Press, Washington DC.

Palm C, Sanchez P, Ahamed S, Awiti A (2007) Soils: A contemporary perspective. *Annual Review of Environmental Resources* **32,** 99-129.

Roscoe R, Buurman P, Velhorst EJ, and V. C.A (2001) Soil organic matter dynamics in density and particle size fractions as revealed by the $^{13}C/^{12}C$ isotopic ratio in Cerrado's Oxisol. *Geoderma* **104,**185-202.

Schulp CJE, Veldkamp A (2008) Long-term landscape – land use interactions as explaining factor for soil organic matter variability in Dutch agricultural landscapes. *Geoderma* **146,** 457-465.

Swift MJ, Shepherd K (2007) Saving Africa's soil: Science and technology for improved soil management in Africa. World Agroforestry Centre, Nairobi.

UNEP (in press) Land Health Surveillance: An Evidence-Based Approach to Land Ecosystem Management. Illustrated with a Case Study in the West Africa Sahel. Nairobi.

Vagen T, Walsh M, and Shepherd K (2006) Stable isotopes for characterisation of trends in soil carbon following deforestation and land use change in the highlands of Madagascar. *Geoderma* **135,**133-139.

Verchot L, Mackensen J, Kandji S,Van Noordwijk M, Tomich T, Ong C, Albrecht A, Bantilan C, Anupama KV, Palm C (2005) Opportunities for linking adaptation and mitigation in agroforestry systems *in* Robledo C, Kanninen M, Pedroni L, editors. Tropical forests and adaptation to climate change: In search of synergies. Center for International Forestry Research (CIFOR), Bogor.