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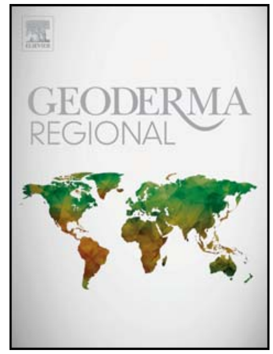

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Soil organic fractions in cultivated and uncultivated Ferralsols in Uganda

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Abstract

Ferralsols are chemically poor soils, with management challenges associated with soil fertility heterogeneity and nitrogen limitations. Proper assessment of soil organic matter fractions can be instrumental in understanding the causes of limited nitrogen supply, and thus addressing soil fertility heterogeneity. A study was conducted in cultivated and uncultivated Ferralsols, in order to assay soil organic carbon (SOC), its particle-size fractions and their influence on soil fertility heterogeneity across small farms in central Uganda. Soil samples were taken from the 0-15 and 15-30 cm depth from 30 cultivated fields classified as of low, medium and high fertility, and from two nearby sites in a native shrubland as references. Soil samples were physically fractionated into sand (2000-63 µm), silt (63-2 µm) and clay (<2 µm). Total SOC and N were analyzed in bulk samples and each size fraction, and the Carbon Management Index (CMI), a widely used indicator of soil quality, was calculated for each field. The CMI in cultivated soils was far below the 100% in reference soils, reaching 34.7, 40.3 and 87% in low, medium and high fertility fields, respectively. SOC and N concentrations decreased in particle-size separates in the order clay>silt>sand. The SOC pool and N in the clay-sized fraction were correlated to soil fertility indicators. More N was stored in the silt + clay size fractions, a generally more stable pool, than in the more labile sand-sized pool. The SOC pool in sand size fractions was far below in low and medium fertility soils than in a reference uncultivated soil. Thus, the sand-sized pool emerged as the most likely cause of limited N supply in a cultivated low-input Ferralsol in Uganda.

Keywords: Particle-size fractionation, soil organic carbon, nitrogen, tropical soils.

Introduction

Poor chemical fertility in Ferralsols is often the major cause of low crop productivity for millions of low-input smallholder farmers in sub-Saharan Africa. Ferralsols are highly weathered soils, with high contents of Fe and Al sesquioxides, and are inherently low in nutrient retention and cation exchange capacity (IUSS Working Group, 2006; Steiner et al., 2007; van Breemen and Buurman, 1998). Ferralitization is common in such soils under warm, humid and sub-humid climates, which promote fast weathering of non-resistant minerals in sand and silt particles. In addition, such process results in strong leaching of cation bases and accumulation of stable secondary minerals such as Fe + Al oxides in the clay fraction, thus negatively influencing soil chemical fertility (Neufeldt, 1999). This natural process has been aggravated by farmers' practices of continuous low-input and continuous cultivation, resulting in physical breakdown of soil aggregates, and in the depletion of soil organic carbon (SOC) and nutrient reserves (African Agriculture Status Report, 2013; Musinguzi et al., 2014). Low SOC concentrations and reduced nutrient retention capacity further increase leaching of applied nutrients and leads to land abandonment by farmers (Renck and Lehmann, 2004; Sanginga and Woomer, 2009). However, farmers have responded to consequences of low SOC and soil fertility by application of different organic amendments, which result in highly variable N concentrations in such tropical farming systems. As a consequence, there is wide soil fertility heterogeneity across the small-sized farms in the African tropics (Ebanyat, 2009; Musinguzi et al., 2013; Tittonell et al., 2007). Recent studies on N response in maize registered a weak relationship between SOC concentration and N recovery efficiency, suggesting low N mineralization, although other conditions such as the particle-size distribution of bulk soil and total SOC may have had confounding effects (Kaizzi et al., 2012). Furthermore, there is limited knowledge on which particle size fraction of SOC is most related with N supply and soil fertility in general, and how continuous cultivation affects the distribution of SOC and N in highly weathered Ferralsols in Africa. Such research efforts would certainly improve the understanding of SOC and N cycling dynamics in Ferralsols, and provide insights on the best approach to address major nutrient limitations. The current literature is not conclusive on this issue, with several studies indicating that the labile SOC associated with sand-sized fractions is the most influential to C and N cycling (Bayer et al., 2001; Gregorich and Janzen, 1996; Lehmann et al., 1998), while others have suggested a strong role of less labile organic fractions associated with silt- and clay-sized particles (Christensen, 2001; Feller and Beare, 1997; Gregorich et al., 2006; Lehmann et al., 2001). Thus, there is a continuous debate among researchers regarding linkages between soil texture, mineralogy, SOC fractions and N cycling. This work aimed at the identification of the SOC fraction(s) most influential in N supply and soil fertility, and understanding how these fractions are affected by continuous cultivation in a highly weathered Ferralsol. Our rationale is to establish a scientifically sound tool to guide decisions for site-specific nutrient management and soil fertility restoration. We hypothesized that (i) SOC and N in silt- and clay-sized fractions are more strongly correlated to soil fertility than the sand-sized fraction; (ii) and that the distribution of total SOC across the different particle-size pools is affected by cultivation.

Materials and methods

Study area

The study was conducted in the Lwamata sub-county, Kiboga district, within the Central Wooden Savanna agro-ecological zone of Uganda (Wortmann and Eledu, 1999). In the past, the area was predominantly occupied with banana and coffee plantations, but has recently turned into annual crops. The district experiences a bi-modal rainfall pattern, with total annual rainfall ranging from 1,000-1,400 mm. The dominant soils are Acric Ferralsols, typically with low CEC, pH and <50% base saturation (IUSS Working Group, 2006).

This area was selected because, according to District Agricultural and Planning authorities, this sub-county experiences low soil fertility challenges (Personal communication). Two major maize producing parishes were selected in four villages, that is, Ssinde (Lwamirindo and Kagererekamu villages) and Buninga (Kikalaala and Kigatansi villages). The villages in Ssinde and Buninga have altitudes ranging between 1,206-1,250 and 1,113-1,158 m a.s.l, respectively; and all lie within latitudes and longitude of about 0°53'02.33" N 31°50'12.48" E (Ssinde) and 0°54'41.55" N 31°49'52.52" E (Buninga). A total of 30 farmers' fields were selected, and an extra two sites under uncultivated shrubland were bench-marked as reference sites. Farmers were instrumental in identifying fields initially believed to have poor, medium and high fertility, each group comprising 10 fields. Using field observations and a clinometer, the topographic position of the selected sites was characterized and slope gradients were measured. According the farmers, most soils had been under continuous cultivation for more than 20 years. Land is mainly prepared manually using a hand-hoe. Banana and coffee were the dominant historical land uses. Soils with low fertility were mostly located on the upper slope positions, with slopes ranging between 6-15%.

Soil sampling and analyses

From each selected farmer's field, four soil sub-samples were taken from the 0-15 cm (top soil) and 15-30 lower depth using an auger. The subsamples were thoroughly mixed in a bucket, air-dried and used for laboratory analyses. Soil pH was determined using a pH electrode in a 1:2.5 soil-water mixture (Okalebo et al., 2002). Soil organic carbon and total N were determined using the dry combustion techniques with a Vario EL CN analyser (Diekow et al., 2005). Available P was extracted with the Bray 1 method (Bray and Kurtz, 1945). Exchangeable bases were obtained using the ammonium acetate extraction technique, and determined by flame photometry for K, and atomic adsorption spectrophotometer for Mg and Ca. Soil texture was determined using the hydrometer method (Bouyoucos, 1936). The concentration of SOC in each site was then used to regroup soils into more consistent low, medium and high fertility categories. This was in reference to the national recommended critical SOC of 1.74% (3% soil organic matter), for sustaining crop production in tropical soils (Okalebo et al., 2002). Ten fields were identified for each soil fertility category, that is, low (<1.2% SOC), medium (1.2-1.7% SOC) and high fertility (SOC >1.7% SOC).

Particle-size fractionation of samples (0-15 and 15-30 cm depths) from farmers' fields and the two sites in an uncultivated shrubland was carried out by submerging a 50 g air-dried sample in deionized water for 30 minutes in plastic bottles, and then adding samples 100 ml of 5% sodium hexametaphosphate. The bottles were tightly capped and shaken for 16 hours using an end-over-end shaker, and the resulting suspensions were passed through a set of sieves of 2000, 250 and

63 µm, with help of spraying distilled water and a rubber spatula. The fractions retained on the 250 and 63 µm sieve consisted of coarse and fine sand, respectively, whereas the material passing the 63 µm sieve was the clay + silt suspension. The clay fraction was separated by pouring the remaining clay + silt suspension into the centrifuge bottles and centrifuging at approximately 1,000 rpm for 3 min at 15 °C. After obtaining a clear clay suspension, the clay, silt and combined fine + coarse sand separates were oven-dried at 40 °C and weighed. Total SOC and N concentrations of each size fraction as applied also in bulk soil, were determined using the dry combustion techniques with a Vario EL CN analyser. The sand-sized organic fraction was considered as labile or particulate component of soil organic matter, while silt- and clay-sized fractions as less-labile fractions (Bayer et al., 2001; Christensen, 2001; Feller and Beare, 1997). The C/N ratio was also computed for bulk soil and particle-size fractions.

Computation of Carbon Management Index (CMI)

The CMI was calculated using the physically fractionated carbon as in Equations 1, 2 and 3 (Blair et al., 1995); on the basis of the Carbon Pool Index (CPI) and the Lability Index (LI) (Equation 1). Lability index was computed from the Lability (L) associated with each soil, which in this case is the fraction of the labile C to non-labile C. The LI is a relative index that gives the fraction ($F_{L)}$ of labile carbon (LC) and non-labile carbon (NLC) from a cultivated field, as compared to a similar fraction (F_R) at reference land use (Equation 2). This has been applied as a tool for assessing soil quality in terms of increments of total SOC, considering a shift of C to the labile pool as a result of agricultural practices. High CMI suggests high amounts of carbon associated to sand-sized fraction (labile component), thus high soil quality (Blair et al., 1995; Diekow et al., 2005).

The CPI compares the sample total SOC (mg g^{-1}) with the total SOC (C_R [mg g^{-1}]) in a reference soil (C_R, Equation 3)

CMI = CPI x LI x 100…………..…………..…Equation 1

LI = F_L/F_R………………………..…………Equation 2

CPI = C_L soil /C_R (reference)………..………….Equation 3

Data analysis

Using the GenStat biostatistical software version 13 for windows, soil properties in different fertility categories were analyzed using Analysis of Variance (ANOVA). We again used the ANOVA to test for significant differences of C and N associated with each of the particle-size fractions under the three soil fertility categories. Mean values of soil properties, C and N concentrations in the particle size fraction from different soil fertility categories were compared using the Fisher's Protected Least Significant of Difference (LSD) at 5% level of significance.

Results

Carbon and nitrogen in particle-sized fractions

Soil fertility heterogeneity was evident in all cultivated fields after stratification by SOC concentration limits, although some soil properties such as pH, Bray 1 extractable P, exchangeable K^+ and Ca^{2+}, silt and clay were not significantly different compared across the soil fertility categories ($p>0.05$). Only total SOC, total N, exchangeable Na^+ and Mg^{2+} were significantly different across the soil fertility categories ($p<0.05$). Irrespective of soil fertility status, extractable P was far below the critical concentration of 15 g kg^{-1} designated for tropical soils (Okalebo et al., 2002). Uncultivated soils registered the highest mean SOC concentration of 2.48%, although Bray 1extractable P, total N and exchangeable Ca^{2+} were much lower than in the cultivated soil.

In cultivated fields, there was a positive pattern of significant increase in C concentrations in all particle sizes, with change in soil fertility from low to high (Table 2). This was evident in both the topsoil (0-15 cm) and the lower soil depth (15-30 cm). The observations in the top soil agreed with data in Table 1. For soil N, the positive trend was only significantly detected in the clay-sized fraction in both depths, and this also related well to the differences in bulk soil N (Table 1). In both cultivated and uncultivated soils, SOC concentrations in the clay-sized fractions were at least twice as high as that of sand-sized fractions. This is in accordance with the SOC dilution effect and the high SOC sorption on clays as observed by Zinn et al. (2007). The same occurred for soil N, although with much more intensity, and the clay fraction of cultivated soils showed N concentrations that were at least four times higher than those in the sand fraction. The C/N ratio in clay-sized fraction of cultivated soil was on average 11 to 14, lower than what was registered in sand-sized fraction (29 to 52) (Table 3). The C/N ratio was notably highest in the silt-sized fraction in the lower soil layer (42 to 61). In the top bulk soil, C/N ratio was 9.7 in high fertility and 7.0 in low fertility, but considerably as high as 19.1 in the uncultivated reference soil.

The clay-sized fraction was the largest SOC pool in cultivated soils, ranging between 52.1-61.1% in both depths (Fig. 1), and low fertility soils registered the lowest percent share of C in the sand-sized fraction. However, in the uncultivated soils, the clay-sized SOC pool was generally smaller with slightly more total SOC stored in the sand fraction. In the lower depth, there was a general increase in the importance of the silt-sized SOC pool.

A comparison of the different organic carbon indices in high fertility cultivated soils registered significantly higher CPI, labile C, non-labile C, computed Lability, LI and CMI; than soils of low and medium fertility, demonstrating variations in SOC quality (Table 4). Only soils with medium fertility registered low lability and lability index. The Carbon Management Index (CMI) was far below 100% in all the 30 cultivated fields. The CMI registered was 34.72%, 40.33% and 86.96% for low, medium and high fertility, respectively (Table 4).

Discussion

Carbon and nitrogen in particle-sized fractions

The data presented in this study express important insights on how soil fertility heterogeneity is related to SOC and N dynamics in Africa. Routine soil tests in bulk samples were clearly inefficient to pinpoint soil fertility variability, since pH, extractable P, exchangeable K^+ and Ca^{2+}, and texture varied little among categories. This is perhaps a consequence of inherently low available P, cation exchange capacity and pH values as typical diagnostic attributes of Ferralsols (IUSS Working Group, 2006). However, the significant difference of SOC across the soil fertility categories was used as criteria for ranking the soil, notwithstanding total N that proved to be a good parameter for fertility ratings. This not only agrees with the farmer-induced heterogeneity due to management widely reported in Sub-Saharan Africa (Musinguzi et al., 2013; Tittonell et al., 2008; Vanlauwe et al., 2007), but also stresses the importance of SOC as a prime indicator of soil quality and of N as the most likely limiting factor for yield in the region. SOC is widely known for its positive influence on aggregate stability, cation exchange and water holding capacity, infiltration, percolation and consequently on soil productivity (Feller and Beare, 1997; Gregorich et al., 2006).

The observed trends of SOC in particle-size fractions agree with those reported on a Xanthic Ferralsol by Lehmann et al. (2001), who found high SOC concentrations in both clay- and silt-sized fractions. In clay-sized fractions, high SOC and N concentrations, when compared with the sand-sized-fraction in both cultivated and uncultivated soils, follow a typical pattern involved in C and N cycling. Highly-weathered soils such as Ferralsol are marked by moderate to high clay contents, typically rich in Fe and Al oxides, with variable charges. Thus, the clay fraction is often able to adsorb plant-derived aromatics or microbial products (Zinn et al., 2007) across a disparate range of chemical functions and electrical charges. In consequence, the clay is often the richer fraction in SOC, especially in soils with moderate clay contents such as those observed in this study. In addition, some studies in tropical soils assert a direct relationship between SOC and clay contents (e.g., Feller and Beare, 1997). However, in the present work, soils have the same textural class, which suggests that SOC variability was driven by human-induced practices such as cultivation and use of organic amendments. In fact, base cations and P concentrations were higher in cultivated than in uncultivated soils, which can be ascribed to some organic fertilizer applications, although this can hardly occur with enhanced SOC depletion due to aggregate disruption by tillage (Zinn et al., 2005).

The SOC concentrations in particle-size fractions are, however, less indicative of SOC retention than the relative pools. The dominant role of the clay-sized fraction in total SOC retention in cultivated soils is shown in Fig. 1 and it is clear that SOC bound to silt and especially clay were lost. Similar trends were noted in the 15-30 cm depth, although the silt-sized fraction was more important than in the topsoil. The fact that considerable amounts of SOC are stored in the clay sized particle-size explains why bulk SOC and clay contents are related (Zinn et al., 2007), and why Ferralsols are believed to be resilient soils for crop production (Zinn et al., 2005). It is noteworthy that most bars in Fig. 1 do not reach 100% due to the variable recovery of the total SOC after the particle-sized fractionation, and the non-recovered SOC can be safely ascribed to the clay fraction adoption characteristics as well-described by Zinn et al., (2007). The data in the present study supports the stated hypothesis (i) that SOC and N in silt- and clay-sized fractions are more important to overall soil fertility than the sand-sized fraction. In addition, there is support to hypothesis (ii), which stated that the distribution of SOC across particle-size fractions is influenced by cultivation, since the clay-sizes SOC pool is relatively lower in uncultivated soils.

All cultivated soils had a CMI <100%, implying lower amounts of labile C (sand-sized C) and thus a likely poor SOC quality. Organic material applications by farmers in high fertility cultivated soils could not boost the sand-sized C (labile C) to be higher than what was registered in uncultivated soil. This showed that cultivation is key factor resulting in carbon breakdown and loss; thus changing to minimal tillage approaches may be attractive for C sequestration (Diekow et al., 2005). However, the lability indices provide a good basis to detect the changes in active pools of cultivated soils, and this emerged crucial for monitoring short- to medium-term N supply, that would otherwise be difficult using total SOC concentrations and the CPI. In the present study, potential N limitations can be associated with low N supply from low carbon concentrations associated with sand-sized/labile pool, with or without cultivation. In addition, the cultivated soils in low input systems often lack sufficient residue incorporation, which is critical since this is a key entrance pool for building sand-sized SOC pools. The ratio of labile C to non-labile C (lability) further reflected the aforementioned challenge, and this ratio was far less than

50%, clearly demonstrating the dominance of the non-labile C, and the likely less effectiveness of the active pool in N cycling. In order to improve this labile N pool, judicious use of organic amendments such as cattle manure, adoption of soil conservation practices such as minimal cultivation must be adopted, in accord with the Integrated Soil Fertility Management approach (Musinguzi et al., 2013; Vanlauwe et al., 2007).

The low SOC and N concentration in the sand-sized fractions, as well as the small relative pools in this size somehow contrasts with the often assumed important role this fraction exerts on N cycling in the tropics (Olk and Gregorich, 2006). The computed C/N ratio of the sand fraction in top soil was higher (29 to 52) than in the clay-sized fraction (Table 3), which is coherent with the fact that this fraction is composed of particulate organic matter. The increased in C/N ratio in silt-sized fraction in the lower soil layer (15-30 cm) suggests impacts of cultivation, increasing the distribution of C that does not easily mineralise. However, these observations must not be considered evidence that coarse-sized SOC are more resistant to decomposition and thus limit N supply. In the top soil layer, the high C/N occurs because, in contrast with the clay-sized organic fraction, there is no possibility of forming mineral-organic complex in the sand size, that could stabilize organic matter (Christensen, 2001). Besides, the low C/N ratio in the clay fraction indicates the high humification degree of constituent organic carbon (Christensen, 2001). Haynes (2005) described the sand fraction as the most sensitive pool to soil management, and indeed our data clearly show that this pool was preferentially depleted in cultivated soils, a tendency that has been observed in tropical climate (Diekow et al., 2005). In consequence, continuous cultivation in the smallholder farming systems can easily disrupt this labile C component, resulting in overall decline in soil quality.

It was also evident that the clay-sized fraction is even more important for the retention of N than for SOC. This can perhaps be related to the mechanisms through which SOC is adsorbed by clay minerals, chiefly kaolinite and oxides in Ferralsols (IUSS Working Group, 2006; Steiner et al., 2007; van Breemen and Buurman, 1998). The low N concentrations in the silt and especially the sand fractions, could be attributed to low mineralization; and the little N released can be easily lost due to the high precipitation patterns in the region, even in the uncultivated soils (van Keulen, 2001). This trend suggests that the clay-sized fraction is the main N pool in soils and perhaps the main source of N to plants in low-input, cultivated soils. Consequently, clay-sized SOC can be the fraction most related with chemical fertility, notwithstanding some assertions that this would be a rather recalcitrant or passive pool, unlikely to affect soil productivity within certain agro-ecological zones (Weil et al., 2003). Further studies are needed to explore N release mechanisms from the silt and clay fractions to further improve the understanding of N retention and dynamics in the tropical soils of Africa.

Conclusion

The bulk soil concentration of SOC is the most consistent indicator of soil fertility and quality in the studied Ferralsols, but this SOC is distributed among particle-size fractions which have very different properties and relative importance. The clay-sized fraction holds most of the total SOC and N in cultivated soils, and is probably the most important size fraction affecting soil fertility in general. On the contrary, low SOC and N concentrations in the sand-sized fraction can be a common cause of N limitations in cultivated and even uncultivated Ferralsols. Practices that preserve the clay- and silt-sized organic fractions C while increasing SOC pools in the sand size are the best options to enhance N supply and crop productivity in the studied Ferralsols.

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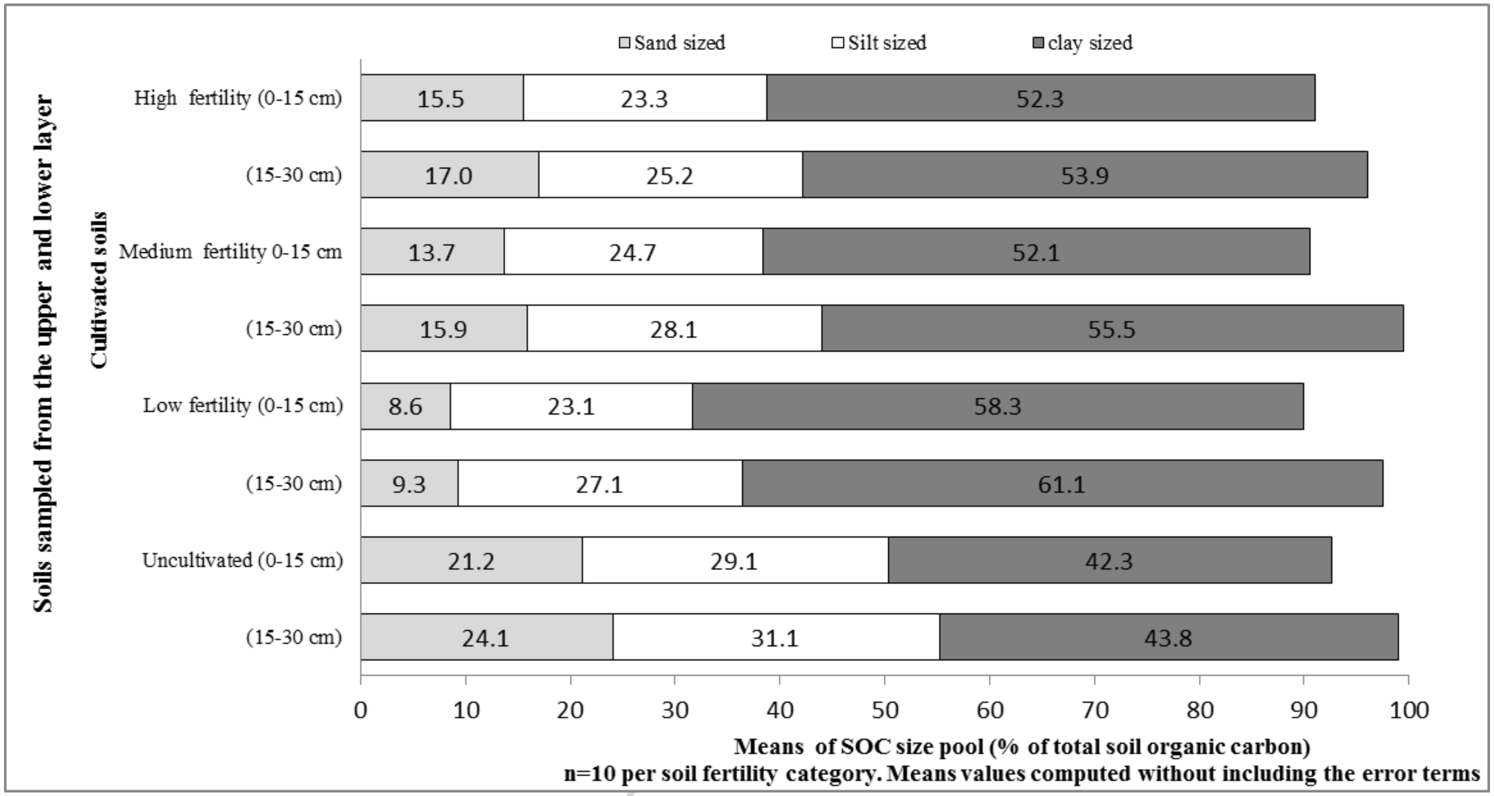

Figure 1. Per cent share of carbon in particle-sized fractions as related to total SOC in the bulk soils of variable fertility sampled at 0-15 and 15-30 cm in a cultivated (n=30) and uncultivated (n=2) Ferralsol in Uganda.

Table 1. Mean values of soil properties in 0-15cm topsoil for soil fertility categories derived using SOC; Low fertility (<1.2% SOC), Medium fertility (1.2-1.7% SOC) and High SOC (>1.7%) for 30 cultivated and 2 uncultivated sites of a Ferralsol in Uganda

	pH (H_2O)	Total SOC	Total N	Extractable P (Bray 1)	K+	Na+	Ca^{2+}	Mg^{2+}	Silt	Clay
		------ %------		mg kg^{-1}	--------------------cmol(+) kg^{-1} soil--------				----%-	
Cultivated soils										
Low fertility	5.54a	0.98a	0.14a	5.3a	0.22a	0.073a	3.89a	1.43a	12.5a	21a
Medium fertility	5.41a	1.39b	0.19b	9.5a	0.22a	0.101a	4.61a	1.46a	17.6a	22a
High fertility	5.72a	1.94c	0.20b	11.3a	0.34a	0.106b	5.01a	1.94b	16.8a	24a
LSD at 5%	0.31	0.16	0.03	6.38	0.15	0.03	1.24	0.19	5.84	7.84
Uncultivated soil										
	6.8	2.48	0.13	5.18	0.52	0.08	2.4	1.9	20	24

LSD=Least Significant Difference, while a, b, c letters represent soil properties that are significantly different across low, medium and high soil fertility categories ($p<0.05$). Each fertility category consisted of 10 cultivated sites. Same letters along a column represent no significant differences observed on comparing means using the LSD.

Table 2. Carbon and Nitrogen concentration in sand-sized (63-2000 µm), silt-sized (2- 63µm) and clay-sized (<2 µm) fractions as influenced by soil fertility heterogeneity in a cultivated and uncultivated Ferralsol in Uganda.

	C and N in particle sized fractions (g kg^{-1} fraction)					
	C-Sand	C-Silt	C-Clay	N-Sand	N-Silt	N-Clay
	(63-2000 µm)	(2-63 µm)	(<2 µm)	(63-2000 µm)	(2-63 µm)	(<2 µm)
Cultivated soils						
0-15 cm						
Low fertility	1.86 a	2.51a	5.42a	0.045a	0.146a	0.519a
Medium fertility	2.14a	3.72 a	7.86b	0.073a	0.157a	0.787b
High fertility	4.52 b	4.77b	10.74c	0.087a	0.198a	0.965c
LSD at 5%	0.61	1.32	2.61	0.04	0.08	0.07
CV	37	21.4	32.4	16.9	32	22.8
15-30 cm						
Low fertility	2.92a	4.42a	5.91a	0.106a	0.073a	0.429a
Medium fertility	3.12a	7.04b	9.68b	0.113a	0.119a	0.708b
High fertility	3.43a	7.12b	9.4b	0.109a	0.17b	0.824c
LSD at 5%	0.81	1.33	2.51	0.04	0.082	0.101
CV	41.1	20.4	23	19.5	24.6	34.3
Uncultivated soils (n=2)						
0-15 cm	5.12	6.07	13.11	0.11	0.141	0.61
15-30 cm	4.13	7.10	12.31	0.13	0.160	0.82

LSD=Least Significant Difference, while a, b, c letters represent C and N significantly different across low, medium and high soil fertility categories ($p<0.05$). Each fertility category consisted of 10 cultivated sites. Same letters along a column represent no significant differences observed on comparing means using the LSD. Uncultivated soils were from the shrubland.

Table 3. Computed C/N ratio derived from C and N concentrations of particle size fractions as influenced by soil fertility heterogeneity in a cultivated and uncultivated Ferralsol in Uganda

	Sand-sized (63-2000 µm)	Silt-sized (2-63 µm)	Clay-sized (<2 µm)
Cultivated soils			
0-15 cm			
Low fertility	41	17	10
Medium fertility	29	24	10
High fertility	52	24	11
15-30 cm			
Low fertility	28	61	14
Medium fertility	28	59	14
High fertility	31	42	11
Uncultivated soils (n=2)			
0-15 cm	47	43	21
15-30 cm	32	44	15

Each fertility category consisted of 10 cultivated sites and two uncultivated soils from the shrubland taken as references.

Table 4. Carbon Pool Index (CPI), Carbon Lability (L), Lability Index (LI), and Carbon Management Index (CMI) as influenced by soil fertility heterogeneity in 0-15 cm of a cultivated and uncultivated Ferralsol in Uganda

	----------------Means of organic carbon parameters				------------------------	--------Calculated organic indices----		
	Total SOC	CPI	Negative Change in SOC (from reference soil)	Labile C	Non-labile C	L	LI	CMI (%)
	g kg^{-1}soil		%	----g kg^{-1} fraction---------				%
Cultivated soils								
Low fertility	9.8a	0.396a	60.48a	1.86a	7.93a	0.23	0.879	34.72
Medium fertility	13.9b	0.56b	43.95b	2.14a	11.14a	0.19	0.72	40.33
High fertility	19.4c	0.782c	21.77ab	4.52b	15.23ab	0.29	1.11	86.96
LSD at 5%	1.63	0.097	17.22	1.26	5.66			
Uncultivated soils	24.8	1	5.12	19.18	0.27			100

Where CPI=Carbon Pool Index= (SOC in cultivated soil/total SOC in uncultivated); L (Lability) =Labile C/Non-Labile C; where the non-labile is referred as silt + clay C, and labile C is referred as Sand C. Lability Index (LI) = Lability in cultivated soil/Lability in uncultivated soil; The CMI (Carbon Management Index) = CPI X LI X 100. LSD= Least Significant Difference for separation of means at 5% level of significance. Each fertility category consisted of 10 cultivated sites. Two uncultivated soils from the shrubland were taken as references.

Highlights

- 30 cultivated soils with variable fertility were compared with 2 uncultivated soils
- Cultivated Ferralsols are significantly depleted of active C fractions
- Nitrogen is tied in clay-sized fraction in both cultivated and uncultivated soil
- Carbon in clay-sized fraction significantly influence variable soil fertility
- Carbon distribution decrease in the order of clay-size>silt-size>sand-sizes