Geoderma Regional 4 (2015) 108–113

Contents lists available at ScienceDirect

Geoderma Regional

journal homepage: www.elsevier.com/locate/geodrs

Soil organic fractions in cultivated and uncultivated Ferralsols in Uganda

Patrick Musinguzi [a,*], John Stephen Tenywa [a], Peter Ebanyat [a], Twaha Ali Basamba [a], Moses Makooma Tenywa [a], Drake N. Mubiru [b], Yuri L. Zinn [c]

[a] Department of Agricultural Production, Makerere University, P.O. Box 7062, Kampala, Uganda
[b] National Agricultural Research Laboratories-Kawanda, P.O. Box 7065, Kampala, Uganda
[c] Department of Soil Science, Federal University of Lavras. Campus, Lavras, MG 37200-000, Brazil

ARTICLE INFO

Article history:
Received 17 September 2014
Received in revised form 12 January 2015
Accepted 13 January 2015
Available online 15 January 2015

Keywords:
Particle-size fractionation
Soil organic carbon
Nitrogen
Tropical soils

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 depths from 30 cultivated fields classified as of low fertility, medium fertility 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 cultivated low-input Ferralsols in Uganda.

1. 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 lead 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

* Corresponding author.
E-mail address: musipato@yahoo.com (P. Musinguzi).

http://dx.doi.org/10.1016/j.geodrs.2015.01.003
2352-0094/

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 highly weathered Ferralsols. 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.

2. Materials and methods

2.1. 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 1000–1400 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 1206–1250 and 1113–1158 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 extra two sites under uncultivated shrubland were bench-marked as reference sites. Farmers were instrumental in identifying fields initially believed to have poor fertility, medium fertility 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 to 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%.

2.2. 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 depths 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 analyzer (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 fertility (<1.2% SOC), medium fertility (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 min in plastic bottles, and then adding samples of 100 ml of 5% sodium hexametaphosphate. The bottles were tightly capped and shaken for 16 h using an end-over-end shaker, and the resulting suspensions were passed through a set of sieves of 2000, 250 and 63 μm, with the help of spraying distilled water and a rubber spatula. The fractions retained on the 250 and 63 μm sieves consisted of coarse sand 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 1000 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 analyzer. 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.

2.3. Computation of Carbon Management Index (CMI)

The CMI was calculated using the physically fractionated carbon as in Eqs. (1), (2) and (3) (Blair et al., 1995); on the basis of the Carbon Pool Index (CPI) and the Lability Index (LI) (Eq. (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 (Eq. (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 total SOC (mg g^{-1}) from a cultivated soil (C_S) with total SOC (C_R [mg g^{-1}]) in a reference soil (C_R, Eq. (3))

$$\mathrm{CMI} = \mathrm{CPI} \times \mathrm{LI} \times 100 \tag{1}$$

$$\mathrm{LI} = F_L / F_R \tag{2}$$

$$\mathrm{CPI} = C_S(\text{cultivated soil}) / C_R(\text{reference soil}). \tag{3}$$

2.4. 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 and 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.

3. Results

3.1. 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