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Land use effects on soil organic matter properties of chromic luvisols in semi-arid northern Tanzania: carbon, nitrogen, lignin and carbohydrates

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Abstract

In the semi-arid part of northern Tanzania, the native tropical woodland is undergoing a rapid conversion into agricultural land. This has resulted in drastic ecological changes in the region. This study was undertaken to investigate the effects of these changes in land use systems on the amount and composition of SOM in bulk soil samples and size separates. Samples were collected from the upper 10 cm of a native tropical woodland, a degraded woodland, 3 and 15 years cultivated fields and home-stead fields where animal manure was regularly applied. Carbon, N, lignin derived phenols and non-celulosic carbohydrates were determined in the samples. Clearing and cultivation of the tropical woodland resulted in a decline of SOM contents in bulk soils and in all size separates. A 56% reduction of C and a 51% reduction of N contents were observed in bulk soils of the cultivated fields. A rapid decline in C and N in coarse and fine sand fractions occurred during the first 3 years of cultivation. The reduction of stable SOM, i.e., the SOM which was in intimate association with the silt and clay sized fractions was relatively small. These results show the importance of organo-mineral associations in stabilization of SOM in soils of the semi-arid tropics. However, a more pronounced decline of stable SOM, especially from the clay, was observed in the 15 years than in the 3 years cultivated fields. These indicate that SOM losses due to cultivation of the native soil may not level off in the near feature. A decline in labile fractions of SOM was found in soils of the degraded woodland. Application of manure increased SOM in bulk soil and in the stabile fractions. An increasing degree of SOM humification with decreasing particle size separates was indicated by C/N ratios and by lignin and carbohydrate signatures. The carbohydrate signatures indicated a direct input of fresh plant residue into the mineral soils of the cultivated fields compared to the native woodland. Therefore, there is a need to develop sustainable soil management and cropping practices to combat the ongoing soil degradation and improve soil fertility in the region.

Keywords: Soil organic matter; Particle size separates; Neutral sugars; Uronic acids; Manure; Land use systems

1. Introduction

Many tropical soils are poor in nutrients and rely on the recycling of nutrients from soil organic matter (SOM) to maintain crop productivity. The SOM encompasses plant, animal and microbial residues in all stages of decay and a diversity of heterogeneous organic substances intimately associated with inorganic soil components (Christensen, 1992). Due to the complex interactions of biological, chemical and physical processes in soil, the turnover of the different SOM components varies continuously.

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The ability to quantify SOM fractions is important for understanding SOM dynamics under different land use systems and for adoption of environmentally sound and sustainable systems. Changes of land use and management practices influence the amount and rate of SOM losses (Guggenberger et al., 1994, 1995). For example, a 20–50% reduction of SOM has been reported by Sombroek et al. (1993) as a result of clearing tropical forests and their subsequent conversion into farm land.

The native tropical woodland in the semi-arid part of northern Tanzania is undergoing a rapid conversion into agricultural land. In addition, acacia (*Acacia tortilis* L.) stands are selectively deforested for the production of charcoal which may have an impact on SOM contents. The effects of these changes on SOM quantity and quality are not well understood. Since SOM is an important factor influencing soil fertility, this lack of understanding may affect the proper management of soils in this region for agricultural purposes.

Various methods have been used to describe SOM quality. Recently, there has been a great interest in physical fractionation of soil according to particle size separates combined with chemical, biological, and physical analysis which allows further insight into the functional attributes of the fractions (Christensen, 1992). Alkaline CuO-oxidation, and trifluoroacetic acid (TFA) hydrolysis are a suitable approach to follow the alteration of lignin and carbohydrates in soil particle size separates with changes in land use (Guggenberger et al., 1994, 1995).

The objectives of this study were to investigate the influences of different land use systems on the content and composition of SOM in bulk soil and size separates in comparison to the native tropical woodland under the semi-arid tropical environment.

2. Materials and methods

2.1. Site description

The study site is located in the Naberera area of the Masai plains in the northern Tanzanian dry belt which extends from 36–38° east to 3°20′–6° south. The topography of the area is characterized by vast plains (1200 –1400 m a.s.l) with scattered stony outcrops, inselbergs and mountain ridges up to 1800 m a.s.l. Mean annual precipitation ranges between 500–600 mm with a maximum between December and April. Mean annual temperature is 20°C. The soils of the area are classified as chromic luvisols according to FAO/UNESCO (1988) with a sandy-loam texture and reddish color. Basic soil characteristics are described in detail in another publication (Solomon et al., 1999). The native woodlands of northern Tanzania support a variety of vegetation types ranging from commiphora, acacia, balanites to pennisetum (Ibrahim and Ruppert, 1995).

The land use systems investigated were a native tropical woodland (Woodland Natv.), a degraded woodland where the acacia trees were deforested for charcoal production (Woodland Degr.), 3 years cultivated fields (Cultiv. 3 year), 15 years cultivated fields (Cultiv. 15 year) and a traditionally managed home-stead fields where animal manure was regularly applied for about 10 years followed by 5 years of bare fallow (Manure). In the cultivated fields, maize (*Zea mays L.*) and beans (*Phaseolus vulgaris L.*) were grown without nutrient inputs. Crop residues that remain on the fields after animal grazing are normally incorporated in to the soil. Composite samples in four replicates, each consisting of 10 subsites were collected from the upper 10 cm of the different land use systems in a radial sampling scheme (Wilding, 1985) in March, 1997. The samples were air dried and sieved (<2 mm) prior to fractionation and chemical analysis.

2.2. Particle size fractionation

Particle size fractionation was conducted on <2 mm material (bulk soil) according to Amelung et al. (1998). After visible root remnants were removed, 30 g of soil was treated ultrasonically with an energy input of 60 J mL^{-1} using a probe type sonicator (Branson Sonifier W-450) in a soil : water ratio of 1 : 5. The coarse sand fraction (250–2000 μm) was isolated by wet sieving. In order to completely disperse the remaining material in the <250 μm suspension, ultrasound was again applied with an energy input of 440 J mL^{-1} in a soil : water ratio of 1 : 10. The clay fraction (<2 μm) was separated by repeated centrifugation. The silt (2–20 μm) and fine sand (20–250 μm) fractions were separated by wet sieving. The recovery of size fractions after ultrasonic dispersion, wet sieving and centrifugation ranges from 963 to 989 g kg^{-1} of the initial soil mass. All fractions were dried at 40°C before grinding them for chemical analysis.

2.3. Chemical analysis

Carbon and nitrogen contents of the bulk soil and particle size separates were analyzed by dry combustion with a C/N/H/S-analyzer (Elementar, Vario EL). Amounts and state of oxidative decomposition of lignin were estimated from alkaline CuO oxidation (Hedges and Ertel, 1982). Samples were oxidized with CuO and 2 M NaOH for 2 h at 170°C under a N_2 atmosphere. Phenolic CuO oxidation products were analyzed by capillary gas–liquid chromatography (HP 5890, HP Ultra 2 fused silica column) equipped with FID detector. Ethylvanillin was added as an internal standard before extraction and phenylacetic acid before derivatization in order to determine the recovery of ethylvanillin. The sum of vanillyl (V), syringyl (S), and cinnamyl (C) units was considered as indicatives of the relative amount of lignin.

Determination of neutral sugars and uronic acids were conducted according to the method of Amelung et al. (1996). Neutral and acidic sugars were liberated from non-cellulosic soil carbohydrates with 4 M trifluoroacetic acid (TFA) at 105°C for 4 h. Before hydrolysis, myo-inositol was added as an internal standard. The hydrolysates were filtered through glass fiber filters and dried using a rotary evaporator. The samples were purified by percolation through XAD-7 and Dowex 50 resin columns. Identification and quantification of sugars was performed by gas-liquid chromathograpy, using 3–O-methylglucose as a recovery standard.

2.4. Statistics

Statistical analysis of the data was carried out in replicates by one-way analysis of variance (ANOVA) using the software package Statistica for windows, (1995). If the main effects were significant at $p < 0.05$, a post hoc separation of means was done by univariate LSD test.

Table 1
Carbon and nitrogen contents (g kg^{-1} soil) and C/N ratios in bulk soils of the different land use systems in northern Tanzania

Land use system[a]	Carbon	Nitrogen	C/N
Woodland Nativ.	18.7a[b]	1.83a	10.2
Woodland Degr.	13.8b	1.22b	11.3
Cultiv. 3 year	8.3c	0.90c	9.2
Cultiv. 15 year	8.2c	0.90c	9.1
Manure	19.2a	1.95a	9.8

[a] Woodland Nativ.–a native tropical woodland; Woodland Degr.–a degraded woodland; Cultivate. 3 year–3 years cultivated fields; Cultivate. 15 year–15 years cultivated fields; Manure–home-stead fields where manure was applied.

[b] Different letters along the column indicate significant differences between the means of the different land use system at $p < 0.05$.

3. Results

3.1. Carbon and nitrogen

The C and N contents of bulk soils of the native tropical woodland (Woodland Natv.) were significantly higher ($p < 0.05$) than the two cultivated fields, i.e., Cultiv. 3 year and Cultiv. 15 year (Table 1). Similar amount of C and N contents were found in bulk soils of the 3 and 15 years cultivated fields. The differences in C and N contents of bulk soils from the native tropical woodland and the fields where manure was applied were not statistically significant.

The contents of C and N in particle size separates from the different land use systems increased in the order: coarse sand < fine sand < silt < clay (Table 2). In the A horizon of these soils, on the average 47% of C and 57% of N were associated with clay, whereas 35% of C and 31% of N were found in the silt. Twelve percent of C and 8% of N were obtained from fine sand, while only 6% of C and 4% of N were found in coarse sand.

Since enrichment factors exclude the effects of different SOM levels associated with the bulk soil (Christensen, 1992), enrichment factors for carbon, $E_C = (g\,C\,kg^{-1}$ fraction)/(g C kg^{-1} bulk soil) and for nitrogen, $E_N = (g\,N\,kg^{-1}$ fraction)/(g N kg^{-1} bulk soil) were calculated to compare the concentrations of C and N in each size separate (Table 3). According to Table 3, higher values of E_C and E_N were obtained from the finer sized particles, i.e., silt and clay, while

Table 2
Carbon and nitrogen contents (g kg^{-1} soil) and C/N ratios in particle size separates of the different land use systems in northern Tanzania

Land use system[a]	Carbon				Nitrogen				C/N			
	CS[b]	FS[b]	Silt	Clay	CS[b]	FS[b]	Silt	Clay	CS[b]	FS[b]	Silt	Clay
Woodland Nativ.	1.64c[c]	2.45b	7.26a	7.45a	0.11d	0.17c	0.73b	0.94a	15.5	14.2	10.0	7.9
Woodland Degr.	0.48d	1.16c	4.74b	7.83a	0.03d	0.07c	0.40b	0.87a	16.6	16.7	11.8	9.0
Cultiv. 3 year	0.50d	1.05c	2.93b	4.16a	0.02d	0.08c	0.29b	0.56a	22.5	12.8	10.2	7.5
Cultiv. 15 year	0.42d	1.05c	2.36b	2.51a	0.02c	0.07c	0.22b	0.34a	18.2	14.4	10.5	7.3
Manure	1.13c	1.23c	4.57b	8.23a	0.05d	0.09c	0.35b	0.89a	22.4	13.3	10.2	9.2

[a] See Table 1 for abbreviations.
[b] CS, coarse sand; FS, fine sand.
[c] Different letters across the row indicate significant differences between the means of different particle size separates within one land use system at $p < 0.05$.

the values of E_C and E_N were low in fine and coarse sand fractions. The C and N contents in particle size fractions of the native woodland were higher than the contents of C and N in the same particle size groups of the cultivated fields (Table 2). In clay and silt fractions, higher C and N contents were obtained from the fields which were cultivated for 3 years compared to the 15 years cultivated fields. Similar amounts of C and N were found in fine and coarse sand fractions of the two cultivated fields. Higher C and N contents were found in all particle size separates of the fields where animal manure was applied than in the cultivated fields.

The C/N ratios of the particle size separates under the different land use systems decreased with decreasing particle size (Table 2). The C/N ratios of clay were lower than the C/N ratios of the bulk soil, while the C/N ratios of the coarse sand, fine sand and silt fractions were generally higher than the C/N values of the bulk soil.

3.2. Lignin

The yields of phenolic CuO oxidation products, i.e., vanillyl, syringyl, and cinnamyl units (g VSC kg^{-1} C) in particle size separates under the different land use systems decreased in the order: coarse sand > fine sand > silt > clay. Relatively higher yields of VSC in bulk soil were obtained from the native tropical woodland (Woodland Natv.) when compared with the values of the other fields. The lowest value was found in the 15 years cultivated fields (Table 4).

The proportion of VSC associated with different size separates within a soil were compared by calculating the enrichment factors for the yields of VSC units, E_{vsc} = (g VSC kg^{-1} C in fraction)/(g VSC kg^{-1} C bulk

Table 3
Enrichment factors for carbon (Ec), and for nitrogen (e_N) in particle size separates of the different land use systems in northern Tanzania

Land use system[a]	E_c[b]				E_N[c]			
	CS[d]	FS[d]	Silt	Clay	CS[d]	FS[d]	Silt	Clay
Woodland Nativ.	0.29 (0.03)[e]	0.64 (0.03)	2.04 (0.07)	1.35 (0.08)	0.19 (0.01)	0.46 (0.02)	2.10 (0.04)	1.75 (0.06)
Woodland Degr.	0.19 (0.01)	0.45 (0.02)	2.72 (0.01)	1.99 (0.04)	0.08 (0.01)	0.35 (0.01)	2.45 (0.03)	2.45 (0.04)
Cultiv. 3 year	0.14 (0.01)	0.42 (0.02)	2.53 (0.01)	1.70 (0.01)	0.07 (0.014	0.26 (0.03)	2.19 (0.03)	2.11 (0.11)
Cultiv. 15 year	0.10 (0.01)	0.36 (0.01)	2.58 (0.01)	2.26 (0.05)	0.07 (0.09)	0.24 (0.01)	2.47 (0.06)	2.84 (0.03)
Manure	0.19 (0.08)	0.18 (0.01)	1.52 (0.08)	2.35 (0.05)	0.08 (0.05)	0.13 (0.01)	1.47 (0.06)	2.50 (0.11)

[a] See Table 1 for abbreviations.
[b] E_c = g C kg^{-1} fraction divided by g C kg^{-1} bulk soil.
[c] E_N = g N kg^{-1} fraction divided by g N kg^{-1} bulk soil.
[d] CS, coarse sand; FS, fine sand.
[e] Values in parenthesis represent the standard error of the mean.

Table 4
Average VSC lignin yields (g kg^{-1} C) in SOM associated in bulk soil and in particle size separates of the different land use systems in northern Tanzania

Land use system[a]	VSC[b]				
	BS[c]	CS[c]	FS[c]	Silt	Clay
Woodland Nativ.	16.5	34.1a[d]	25.9b	14.8c	6.5d
Woodland Degr.	14.1	34.1a	23.5a	10.9b	4.8b
Cultiv. 3 year	12.4	21.9a	16.2a	10.0b	5.0b
Cultiv. 15 year	11.8	22.6a	15.6b	8.5c	4.1d
Manure	13.5	15.8a	20.9b	8.6c	6.3d

[a] See Table 1 for abbreviations.
[b] VSC = vanillyl + syringyl + cinnamyl.
[c] BS, bulk soil; CS, coarse sand; FS, fine sand.
[d] Different letters across the row indicate significant differences between the means of different particle size separates within one land use system at $p < 0.05$.

soil). This excludes the effect of differential recoveries of VSC in soils from different sites. Higher values of E_{vsc} were generally obtained from the SOM associated with coarse and fine sand fractions. The lowest value of E_{vsc} was found in clay fractions (Table 5). The E_{vsc} value of SOM associated with silt was in between the sand sized and clay fractions. The woodlands (Woodland Natv., 2.07 and Woodland Degr., 2.43) had the highest E_{vsc} values, while the lowest value was found in the fields where animal manure was applied (Manure, 1.18).

The (ac/al)v and (ac/al)s ratios in particle size separates generally decreased in the order: clay > silt > fine sand > coarse sand and they were generally higher in the native tropical woodland (Woodland Natv.) than in the cultivated fields (Table 5).

3.3. Carbohydrates

The concentrations of neutral sugars and uronic acids in particle size separates from the different land use systems increased in the order: silt < coarse sand < fine sand < clay (Table 6). Neutral sugars and uronic acids concentrations in bulk soil increased in the order: Manure < Woodland Degr. < Woodland Natv. < Cultiv. 3 year < Cultiv. 15 year, the highest concentrations being found in the cultivated fields.

The ratios between galactose plus mannose to arabinose plus xylose, [(gal + man)/(ara + xyl)] and rhamnose plus fucose to arabinose plus xylose, [(rha + fuc)/(ara + xyl)] can be used to indicate the origin of carbohydrates (Murayama, 1984; Christensen, 1992; Guggenberger et al., 1994, 1995).

Both ratios of [(gal + man)/(ara + xyl)] and [(rha + fuc)/(ara + xyl)] decreased in the order: clay > silt > fine sand > coarse sand (Table 7). Higher ratios of [(gal + man)/(ara + xyl)] and [(rha + fuc)/(ara + xyl)] were found in all particle size separates of soils from the woodlands compared to the cultivated fields. The ratios of the home-stead fields were in between the woodlands and the cultivated fields.

Enrichment of pant derived sugars (arabinose and xylose), E_{PDS} = [g (ara + xyl) kg^{-1} C in fraction]/[g (ara + xyl) kg^{-1} C in bulk soil] and enrichment of microbial derived sugars (mannose, galactose, rhamnose and fucose), E_{MDS} = [g (man + gal + rham + fuc) kg^{-1} C in fraction]/[g (man + gal + rham + fuc) kg^{-1} C in bulk soil] were calculated for the soil particle size separates under the different land use systems. According to Table 8, E_{PDS} values decreased in the order: coarse sand > fine sand > clay > silt. The E_{MDS} values showed the opposite trend. These values generally increased in the order: coarse sand < fine sand < silt <clay. The highest E_{PDS} values were obtained from cultivate fields. The E_{MDS} values peaked in the native woodland.

4. Discussion

4.1. Carbon and nitrogen

The cultivation of native soils, which involves a reduced input of plant residues and a higher soil disturbance, causes a substantial reduction of SOM levels (Dalal and Mayer, 1986). These impacts of cultivation on SOM levels are caused by an increased decomposition rate and redistribution of SOM as a result of interactions of physical, chemical and biological soil processes. The nature of changes induced by cultivation also depends upon particular soil management (Christensen, 1992).

In the present study, a 56% reduction of C and a 51% reduction of N contents were observed in the A horizon of the chromic luvisols as a result of clearing and subsequent cultivation of the native tropical woodland (Table 1). This is in agreement with results

Table 5
Enrichment factors for VSC lignin yields, $(ac/al)_V$ and $(ac/al)_S$ ratios of SOM associated in particle size separates of the different land use systems in northern Tanzania

Land use system[a]	E_{VSC}[b]				$(ac/al)_V$[c]				$(ac/al)_S$[d]			
	CS[e]	FS[e]	Silt	Clay	CSe	FS[e]	Silt	Clay	CS[e]	FS[e]	Silt	Clay
Woodland Nativ.	2.07 (0.06)[f]	1.56 (0.05)	0.89 (0.02)	0.39 (0.02)	0.30 (0.02)	0.31 (0.01)	0.38 (0.01)	0.76 (0.04)	0.37 (0.05)	0.28 (0.01)	0.38 (0.01)	0.45 (0.07)
Woodland Degr.	2.43 (0.06)	1.67 (0.07)	0.78 (0.03)	0.34 (0.02)	0.28 (0.01)	0.27 (0.01)	0.38 (0.01)	0.69 (0.02)	0.32 (0.02)	0.29 (0.02)	0.37 (0.01)	0.42 (0.01)
Cultiv. 3 year	1.77 (0.02)	1.31 (0.03)	0.81 (0.01)	0.40 (0.03)	0.23 (0.03)	0.27 (0.03)	0.36 (0.01)	0.65 (0.03)	0.24 (0.06)	0.26 (0.03)	0.37 (0.01)	0.37 (0.02)
Cultiv. 15 year	1.94 (0.03)	1.34 (0.08)	0.72 (0.02)	0.35 (0.01)	0.23 (0.01)	0.26 (0.04)	0.33 (0.02)	0.66 (0.02)	0.29 (0.01)	0.25 (0.04)	0.37 (0.02)	0.38 (0.01)
Manure	1.18 (0.03)	1.55 (0.03)	0.63 (0.03)	0.47 (0.01)	0.26 (0.02)	0.28 (0.02)	0.50 (0.02)	0.68 (0.03)	0.36 (0.02)	0.32 (0.01)	0.51 (0.02)	0.59 (0.04)

[a] See Table 1 for abbreviations.
[b] $E_{VSC} = \mathrm{g\,VSC\,kg^{-1}\,C}$ in fraction divided by $\mathrm{g\,VSC\,kg^{-1}\,C}$ in bulk soil.
[c] $(ac/al)_V$ = ratio of vanillic acid to vanillin.
[d] $(ac/al)_S$ = ratio of syringic acid to syringaldehyde.
[e] CS, coarse sand; FS, fine sand.
[f] Values in parentheses represent the standard errors of the mean.

Table 6
Amounts of neutral sugars and uronic acids ($g\,kg^{-1}$ C) in SOM associated in bulk soil and in particle size separates of the different land use systems in northern Tanzania

Land use system[a]	Neutral sugars					Uronic acids				
	BS[b]	CS[b]	FS[b]	Silt	Clay	BS[b]	CS[b]	FS[b]	Silt	Clay
Woodland Nativ.	103.9	83.5b[c]	91.0b	79.1b	131.4a	5.3	5.5ab	6.0ab	4.7b	7.3a
Woodland Degr.	98.7	84.5	92.2	68.7	108.5	5.1	5.9a	5.9a	4.1b	6.8a
Cultiv. 3 year	128.0	100.8b	100.0b	96.7b	172.2a	7.1	6.1	6.1	5.0	8.1
Cultiv. 15 year	134.4	101.3b	98.9b	78.2b	182.8a	8.3	8.8a	8.8a	5.3b	8.8a
Manure	87.1	78.7a	82.2a	30.9b	87.8a	5.0	5.4	5.5	4.2	6.0

[a] See Table 1 for abbreviations.
[b] BS, bulk soil; CS, coarse sand; FS, fine sand.
[c] Different letters across the row indicate significant differences between the means of different particle size separates within one land use system at $p < 0.05$.

Table 7
Ratios of mannose plus galactose to arabinose plus xylose [(Man + Gal)/(Ara + Xyl)] and rhamnose plus fucose to arabinose plus xylose [(Rha + Fuc)/(Ara + Xyl)] in SOM associated with particle size separates of the different land use systems in northern Tanzania

Land use system[a]	[(Man + Gal)/(Ara + Xyl)]				[(Rha + Fuc)/(Ara + Xyl)]			
	CS[b]	FS[b]	Silt	Clay	CS[b]	FS[b]	Silt	Clay
Woodland Nativ.	0.58 (0.01)[c]	0.70 (0.01)	1.54 (0.06)	1.63 (0.06)	0.17 (0.04)	0.30 (0.03)	0.49 (0.11)	0.59 (0.07)
Woodland Degr.	0.31 (0.04)	0.45 (0.09)	1.55 (0.04)	1.76 (0.05)	0.15 (0.01)	0.30 (0.09)	0.28 (0.18)	0.43 (0.10)
Cultiv. 3 year	0.24 (0.03)	0.15 (0.02)	0.84 (0.06)	1.14 (0.01)	0.11 (0.01)	0.12 (0.01)	0.20 (0.13)	0.22 (0.09)
Cultiv. 15 year	0.18 (0.01)	0.39 (0.04)	1.02 (0.05)	1.50 (0.04)	0.10 (0.06)	0.12 (0.01)	0.17 (0.02)	0.30 (0.06)
Manure	0.29 (0.01)	0.65 (0.01)	1.13 (0.05)	1.63 (0.04)	0.11 (0.08)	0.19 (0.01)	0.31 (0.12)	0.46 (0.03)

[a] See Table 1 for abbreviations.
[b] CS, coarse sand; FS, fine sand.
[c] Values in parenthesis represent the standard error of the mean.

reported by other authors (Tiessen and Stewart, 1983; Dalal and Mayer, 1986; Sombroek et al., 1993). Application of manure increased C and N contents in the bulk soil indicating the importance of this practices on the SOM level. An increase of C and N contents in the bulk soil following manure application to sandy loam soils of Askov in Denmark was reported by Christensen (1988). Lehmann et al. (1997) also showed a

Table 8
Enrichment factors for plant derived sugars (E_{PDS}) and microbial derived sugars (E_{MDS}) in SOM associated with particle size separates of the different land use systems in northern Tanzania

Land use system[a]	E_{PDS}[b]				E_{MDS}[c]			
	CS[d]	FS[d]	Silt	Clay	CS[d]	FS[d]	Silt	Clay
Woodland Nativ.	1.26 (0.34)[e]	1.03 (0.20)	0.51 (0.22)	0.98 (0.23)	0.64 (0.07)	0.69 (0.03)	0.56 (0.06)	1.47 (0.06)
Woodland Degr.	1.15 (0.06)	0.98 (0.07)	0.60 (0.04)	0.94 (0.05)	0.32 (0.03)	0.44 (0.07)	0.68 (0.03)	1.17 (0.06)
Cultiv. 3 year	1.36 (0.01)	1.18 (0.06)	0.67 (0.01)	0.96 (0.11)	0.50 (0.03)	0.34 (0.04)	0.75 (0.11)	1.41 (0.05)
Cultiv. 15 year	1.39 (0.04)	1.24 (0.18)	0.63 (0.01)	0.97 (0.05)	0.27 (0.02)	0.43 (0.06)	0.52 (0.05)	1.18 (0.07)
Manure	1.28 (0.31)	1.15 (0.11)	0.37 (0.23)	0.87 (0.37)	0.37 (0.06)	0.67 (0.02)	0.34 (0.05)	1.27 (0.70)

[a] See Table 1 for abbreviations.
[b] E_{PDS} = arabinose + xylose.
[c] E_{MDS} = mannose + galactose + rhamnose + fucose.
[d] CS, coarse sand; FS, fine sand.
[e] Values in parenthesis represent the standard error of the mean.

5–7-fold increase of C and N contents in fields which received goat manure compared to native savanna soils in northern Kenya.

The C and N contents in particle size separates under the different land use systems peaked in clay followed by silt sized fractions. Lower contents of C and N were obtained from the coarse and fine sand sized fractions (Table 2). The proportions of C and N isolated from the different particle size separates were similar to those reported by other authors (Christensen, 1988; Guggenberger et al., 1994).

Soil organic matter associated with silt and clay sized fractions was enriched in C and N, while the SOM associated with fine and coarse sand sized fractions was depleted. The enrichment of silt and clay bound SOM and depletion of SOM associated with sand size fractions were also reported by Zech et al. (1995) for Ultisols under secondary forest in Costa Rica. According to Christensen (1992), SOM associated with sand size fractions mainly consists of macro-organic matter which is not involved in organo-mineral complexes but is partially occluded within aggregates. This macro-organic matter, when compared with silt and clay bound SOM, is much more susceptible to mineralization. The SOM associated with clay and silt size fractions is characterized by an intimate association with the mineral phase.

The C/N ratio generally decreased with decreasing particle size separates indicating an increasing degree of humification (Tiessen and Stewart, 1983; Guggenberger et al., 1994). The changes of the SOM contents induced by different land use systems were not consistently reflected by the C/N ratios. Thus, the C/N ratio of SOM must be considered as less informative indicator of SOM quality than the C and N contents alone (Christensen, 1992).

The distribution of SOM in particle size fractions of the different land use systems showed that clearing and cultivation of the native tropical woodland resulted in a decline of SOM contents in all size fractions. The labile fractions i.e., the SOM associated with coarse and fine sand fractions showed a rapid decline within the first 3 years of cultivation. Deforestation of the acacia trees from the native woodlands led to the reduction of the labile SOM fractions. Tiessen and Stewart (1983) and Christensen (1992) pointed out that since the turnover rate of SOM associated with sand size fractions is fast, the SOM attached with these fractions is rapidly lost. Compared to the labile fractions, the decrease of the stable fractions as a result of cultivation was relatively small. The results indicate that organo-mineral associations play a very important role in SOM stabilization of these soils in the semi-arid tropics. However, a considerable decline in the stable SOM especially from the clay fraction was observed in the fields which were cultivated for 15 years compared to the 3 years cultivated fields. Therefore, with continued cultivation, the SOM in the more stable fractions is also affected. Similar results were reported by Tiessen and Stewart, (1983) for Mollisols in north America. With continued cultivation, a decline in absolute SOM amounts in all size separates was reported for Vertisols in Australia (Dalal and Mayer, 1986).

Application of manure increased the SOM bound in silt and clay fractions of the home-stead fields. Christensen (1988) and Lehmann et al. (1997) reported an increase in SOM associated with silt and clay size fractions following the application of animal manure for soils of Askov in Denmark and for tropical Fluvisols of the semi-arid savanna in northern Kenya, respectively. Incorporation of partially decomposed plant structures and microbial residues together with manure might be accountable for the relative increase in silt and clay bound SOM.

4.2. Lignin

A reduction of CuO oxidation products coupled with an increment of (ac/al)v and (ac/al)s ratios were observed with decreasing particle size separates. These results indicate an increased lignin degradation in the order: coarse sand $<$ fine sand $<$ silt $<$ clay as was shown for Inceptisols in pre-alpine regions of southern Germany (Guggenberger et al., 1994) and for Oxisols under the native savanna in Columbia (Guggenberger et al., 1995). A pronounced enrichment of phenolic CuO oxidation products of the SOM associated in sand size fractions and depletion of the clay fractions in these products were shown by the enrichment factors.

The SOM associated with sand size separate usually resembles unaltered plant residue in its biochemical properties (Christensen, 1992). In the present study, the lignin in the sand size fractions was the least altered by microorganisms compared to the other fractions.

The SOM associated with clay showed a relatively higher degree of microbial alteration of lignin than the silt. The observed patterns are in line with the results of Guggenberger et al. (1994, 1995); Lehmann et al. (1997) and Lehmann et al. (1998) for Acrisols of central Togo.

The degree of microbial alteration of lignin can be demonstrated by the acid to aldehyde ratio of the vanillyl, (ac/al)v and syringyl, (ac/al)s units. Higher (ac/al)v and (ac/al)s ratios indicate an increase in side chain oxidation of the phenyl propane unit (Guggenberger et al., 1994, 1995; Hedges et al., 1988). The observed higher (ac/al)v and (ac/al)s ratios in the native tropical woodland compared to the cultivated fields show that lignin from native tropical woodland was in a more advanced stage of decomposition than lignin from the cultivated fields. Guggenberger et al. (1994) demonstrated that lignin in forest soils can be distinguished from the lignin in agricultural soils by its high (ac/al)v ratios.

4.3. Carbohydrates

The highest concentrations of neutral sugars and uronic acids were generally found in SOM associated with the clay size fraction. The silt fraction was depleted in both neutral sugars and uronic acids compared to the other fractions. This is in agreement with the results of Oades et al. (1987) for Alfisols in Australia, Angers and Mehuys (1990) for Inceptisols in Canada and Guggenberger et al. (1994) for Inceptisols in southern Germany. A depletion of carbohydrates in clay, however, was reported by Dalal and Henery (1988) for tropical soils in Australia. According to Guggenberger et al. (1994), this discrepancy of carbohydrates distribution in particle size separates might be the results of different patterns of mineralization of plant derived sugars and microbial carbohydrate inputs. Generally, higher concentrations of microbially synthesized carbohydrates were reported in finer particle size fractions (Oades et al., 1987; Dalal and Henery, 1988; Guggenberger et al., 1994).

Since TFA does not digest crystalline cellulose, the monosaccarides originate from plant derived hemicellulose and microbial products. Pentoses (arabinose and xylose) are not synthesized by the microorganisms but are important constituents of plant residues (Christensen, 1992; Guggenberger et al., 1995). Microorganisms synthesize large amounts of hexoses (galactose and mannose) and deoxysugars (rhamnose and fucose) (Guggenberger et al., 1995). Under the different land use systems, the SOM associated with the clay fraction was enriched in microbially derived sugars (mannose, galactose, rhamnose and fucose) compared to the other fractions, while the sand size separates were depleted in these sugars. This confirms that the clay fraction was enriched in carbohydrates of microbial origin. On the other hand, coarse and fine sand size fractions were enriched with plant derived sugars (arabinose and xylose), compared to clay and silt sized fractions. Lowest ratios of [(gal + man)/(ara + xyl)] and [(rha + fuc)/(ara + xyl)] in sand and a corresponding highest ratios in clay fractions were reported by Guggenberger et al. (1994, 1995) and Lehmann et al. (1997).

The higher production of microbial metabolites (Guggenberger et al., 1994) and their intimate association and stabilization against mineralization in clay minerals (Oades et al., 1987) could be accountable for the enrichment of microbially derived carbohydrates in clay separates. Guggenberger et al. (1994) suggested that probably due to the weaker adsorption of carbohydrates to silt than to clay size fractions, microorganisms efficiently utilize carbohydrates as a source of energy in silt fractions. In addition, lower production of microbial metabolites might also contribute to the smaller pool of microbially synthesized carbohydrates in silt sized fractions in comparison to clay.

Higher neutral sugars and uronic acids concentrations were found in bulk soil and particle size separates of the cultivated fields than in the native woodland. Kögel-Knabner et al. (1988) and Guggenberger et al. (1994) stated that most plant litter in forest stands enters the soil from above ground and forms a humus layer. In this layer, carbohydrates are preferentially mineralized in the course of humification. Therefore, the SOM coming into the mineral soil of the forest is generally depleted in carbohydrates. In cultivated fields, however, the incorporation of plant residues into the mineral soil occurs directly as rhizodeposits and crop remains. The higher proportions of plant derived sugars were indicators of the direct inputs of fresh crop residues into mineral soil of the cultivated fields.

5. Conclusions

In the semi-arid part of northern Tanzania, clearing of the native woodland and its subsequent conversion into cultivated fields has led to a pronounced decline of the SOM in bulk soils and in all size separates. In addition, the chemical composition of SOM was strongly affected by cultivation of the native soil. The possible reasons for the observed degradation are the reduced return of plant residues and the increased soil disturbance and subsequent mineralization of SOM.

The largest decline of C and N contents occurred from the macro-organic matter which is attached to the fine and coarse sand size fractions in the first 3 years of cultivation. In contrast, the reduction of stable SOM, i.e., the SOM which was in intimate association with the silt and clay sized fractions was relatively small. These results show the importance of organo-mineral associations in stabilization of SOM in soils of the semi-arid tropics. However, a more pronounced decline of stable SOM, especially from the clay, was observed in the 15 years than in the 3 years cultivated fields. These indicate that SOM losses due to cultivation of the native soil may not level off in the near feature.

Selective removal of acacia trees for charcoal production from the native tropical woodland reduced the labile fraction of SOM. Improvement of the stable SOM associated with silt and clay fractions as a result of application of manure followed by bare fallow emphasizes the role of these management practices in SOM build-up. An increasing degree of SOM humification with decreasing particle size separates was indicated by the C/N ratios and by lignin and carbohydrate signatures confirms the findings from other tropical and temperate soils.

On the basis of the above findings, there is a need to develop sustainable soil management and cropping practices to combat the ongoing soil degradation and improve soil fertility in the region. Application of animal manure was shown to be a viable method for improving SOM.

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