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Land use effects on amino sugar signature of chromic Luvisol in the semi-arid part of northern Tanzania

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Abstract Characterizing amino sugar signature in particle size separates of tropical soils is important for further understanding the fate of microbial-derived compounds during the decomposition of soil organic matter (SOM) in tropical agroecosystems. We investigated the impact of land-use changes on the nature, amount and dynamics of amino sugars in soil of the semi-arid northern Tanzania. Samples were collected from the uppermost 10 cm of native woodland, degraded woodland, fields cultivated for 3 and 15 years and homestead fields fertilized with animal manure. The amount of glucosamine, galactosamine, mannosamine and muramic acid were determined in bulk soil and size separates. Compared to the native woodland, a 68% and 72% reduction in total amino sugar contents were found in the 3- and 15-year cultivated fields, respectively. Moreover, 39% of the total amino sugar was lost from the degraded woodland. This may be attributed to accelerated decomposition of amino sugars and/or decreasing microbial biomass input under the semi-arid environment following clear-cutting and cultivation. In contrast, only a 20% decline was found from the fields where animal manure had been applied. Most of the amino sugar depletion occurred from the coarse and fine sand-associated SOM. The decline from the silt and clay-bound amino sugar was relatively small, indicating the importance of organo-mineral associations in the stabilization of microbial-derived sugars in this tropical soil. After 15 years of continuous cultivation, the ratio of glucosamine:galactosamine increased from 1.44 to 2.23, while the ratio of glucosamine:muramic acid increased from 14.5 to 26.5 ($P < 0.05$). These results suggest that cultivation may have led to preferential depletion of bacterial-derived amino sugars (mu-

ramic acid and galactosamine) compared with fungal-derived glucosamine.

Keywords Hexosamine · Muramic acid · Manure · Particle size separates · Soil organic matter

Introduction

Agriculture has claimed a large share of productive terrestrial environment in the tropics and sub-tropics, largely through deforestation of natural forests. The concern over rapid deforestation has prompted studies to determine how the forest ecosystem in the tropics responds to this disturbance (Odum and Pigeon 1970; Zech et al. 1996). Several studies have shown that agricultural management practices influence the amount of organic matter present in the soil and cause changes in the rate of soil organic matter (SOM) turnover. For example, soil organic carbon losses (SOC) ranging from 31% to 59% have been reported as a result of cultivation of native soils for subtropical Vertisols in Australia (Dalal and Mayer 1986) and for tropical Luvisols in Tanzania (Solomon et al. 2000). Moreover, an increase in oxidation and decomposition of humic substances as indicated by elemental and functional group analysis and ^{13}C NMR spectra was observed when native soils were put under cultivation in Argentina (Rosell et al. 1989). However, very little is known about the impact of deforestation and cultivation on the nature, amount and dynamics of microbial-derived SOM in bulk soil and particle size separates under the arid and semi-arid tropical agroecosystems. Thus characterizing amino sugar pools might help for further understanding the fate of microbial-derived compounds during decomposition of SOM in tropical soils.

Physical fractionation of soil according to size separates combined with degradative chemical techniques are useful for evaluating the influence of land use changes in SOM composition (Christensen 1992; Guggenberger et al. 1994, 1995; Zech et al. 1996; Amelung

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1997; Solomon et al. 2000). Guggenberger et al. (1995) and Solomon et al. (2000) demonstrated that decreasing yields of lignin derived phenols and increasing carboxyl functionality of lignin derivatives with decreasing particle size indicate a progressive lignin alteration from the coarser to the finer separates of tropical soils. Similarly, their studies have also revealed that carbohydrates in sand were mainly of plant origin, whereas the carbohydrate in clay-size separates were dominated by microbial-derived sugars. However, these parameters did not differentiate between compounds of different microbial origin.

Amino sugars can provide a clue to such understanding because they are derived from different microbes in the soil (Sowden and Ivarson 1974; Parsons 1981; Zhang et al. 1998; Glaser et al. 2000). Some studies indicated the existence of amino sugars in higher plants (Putsztai 1964; Sharon 1965). However, detailed studies of plant polysaccharides and plant cell walls failed to detect amino sugars in higher plants (Benzing-Purdie 1981). Therefore, amino sugar concentrations can serve as useful indicators for microbial contributions to SOM (Sowden et al. 1978; Benzing-Purdie 1981, 1984; Kögel and Bochter 1985; Amelung 1997; Amelung et al. 1999; Glaser et al. 2000; Zhang et al. 1998). Moreover, the ratio of glucosamine to galactosamine (GlcN:GalN) indicates the relative contribution of fungi-derived sugars (Kögel and Bochter 1985; Amelung 1997; Amelung et al. 1999; Zhang et al. 1998), while the ratio of glucosamine to muramic acid (GlcN:MurA) has been used to evaluate the fate of bacterial-derived amino sugars in the soil by Amelung (1997) and Zhang et al. (1997, 1998).

Therefore, the objective of this study was to evaluate the influence of deforestation and subsequent cultivation of native woodlands on the nature, amount and dynamics of glucosamine, galactosamine, mannosamine and muramic acid in bulk soil and size separates under the semi-arid tropical agroecosystems of northern Tanzania.

Materials and methods

Site description

We studied the soil in the Naberera area of the Masai plains in the northern Tanzanian dry belt which extends from 36–38°E to 3–6°S. The region is a vast plain (1200–1400 m a.s.l.) with scattered stony outcrops, inselbergs and mountain ridges up to 1800 m. The mean annual temperature is 20 °C and the average annual precipitation ranges between 500 and 600 mm with a maximum between December and April. Geologically the area is associated with archaic metamorphic rocks with abundant gneiss, schist and quartzite. The plains consists of deep, well-drained soil with a sandy-loam texture and reddish color which is characterized as chromic Luvisols according to FAO/Unesco classification (1997).

The Naberera area supports a variety of vegetation cover types. Along hillsides, a scattered *Acacia-Commiphora* (*Commiphora schimperi* Engl.) bushes occur together with several succulent species such as *Euphorbia candelabrum* Tremaut ex Kotschy

and *Euphorbia nyikae* Pax ex Engl. The vegetation of the extensive plains ranges from dense *Acacia-Commiphora-Balanites* (*Balanites aegyptiaca* Delile) woodlands to *Pennisetum* (*Pennisetum mezianum* Leeke) grasslands. The original woodland has been degraded in places where the *Acacia* spp. have been cut for charcoal production. Some fields, originally woodland, have been cleared and cultivated for 3 years and some for 15 years. The size of the cultivated fields varies from 1 ha to 5 ha. In addition, there are traditionally managed homestead fields (0.25–0.5 ha) where animal manure has been regularly applied for about 10 years. Maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.) have been grown without fertilizer on the cultivated land. Crop residues that remain after grazing were normally incorporated into the soil.

Sampling

We used a core sampler and collected composite samples in four replicates from the native woodland (Woodland Nativ.), degraded woodland (Woodland Degr.), 3-year cultivated fields (Cultiv. 3 yr.), 15-year cultivated fields (Cultiv. 15 yr.) and from the homestead fields (Manure) in March 1997. We selected four representative sites from each land use and from each site, we collected ten subsamples (200 cm³ core volume at each sub-site) in a radial scheme (Wilding 1985), and bulked them into one sample. The spacing between the sub-sites on the radii ranged from 5 m to 20 m depending on the size of the patches. The samples were air-dried and sieved (<2 mm) prior to fractionation.

Particle size fractionation

Particle size fractionation was done on <2 mm material (bulk soil) according to Amelung et al. (1998). After visible root remnants were removed, 30 g of soil was ultrasonically treated with an energy input of 60 J ml⁻¹ using a probe type sonicator (Branson Sonifier W-450, Branson) in a soil:water ratio of 1:5 (w/v). The coarse sand separates (250–2000 µm) were 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 (w/v). The clay separates (<2 µm) was separated from the silt (2–20 µm) and fine sand (20–250 µm) separates by repeated centrifugation. The silt separates were separated from the fine sand size separates by wet sieving. Coarse and fine sand separates were combined and all fractions were dried at 40 °C before grinding them for chemical analysis. The recovery of the size fractions after ultrasonic dispersion, wet sieving and centrifugation ranged from 96% to 99% of the initial soil mass. All fractions were dried at 40 °C and ground for chemical analysis.

Chemical analysis

Carbon and nitrogen contents of bulk soil and particle size separates were analyzed by dry combustion with a C/H/N/S-analyzer (Elementar Vario EL). The pH (H₂O) and pH (KCl) were determined in 1:2.5 soil:water (w/v) suspension using a pH-meter. Cation-exchange capacity (CEC) was determined with 1 M NH₄OAc (pH 7.0) according to Avery and Bascomb (1974). Dithionite-citrate-bicarbonate extractable aluminum and iron (Al_d, Fe_d) were determined after double extractions at 70 °C for 15 min as described by Mehra and Jackson (1960). Oxalate-extractable aluminum and iron (Al_o, Fe_o) were determined using atomic absorption spectroscopy (Varian AAS-400) after extraction for 2 h with 0.2 M ammonium oxalate at pH3 in the dark (Blume and Schwertmann 1969). Basic physical and chemical characteristics of the soil are presented in Table 1.

Amino sugars (i.e., glucosamine, galactosamine, mannosamine and muramic acid) were determined according to the method of Zhang and Amelung (1996). Soil samples were hydrolyzed with 6 M HCl at 105 °C for 8 h. Before hydrolysis, myo-inositol was

Table 1 Basic physical and chemical properties of the A horizon of the different land use systems in northern Tanzania. *Woodland Nativ.* Native tropical woodland, *Woodland Degr.* degraded woodland, *Cultiv. 3 yr.* 3-year cultivated fields, *Cultiv. 15 yr.* 15-year cultivated fields, *Manure* homestead fields which were fertil-

Land use	CS	FS	Silt	Clay	Bulk density	pH		CEC ($\text{cmol}_c\text{kg}^{-1}$)	BS (%)	SOC N S			C:N	Fe _d Fe _o Al _d Al _o			
	— (g kg ⁻¹) —				(g cm ⁻³)	(H ₂ O) (CaCl ₂)				— (g kg ⁻¹) —				(g kg ⁻¹)			
Woodland Nativ.	287	206	190	295	1.20	6.6	6.0	16.8	85	18.7	1.83	0.28	10.2	1.02	0.24	0.60	0.17
Woodland Degr.	372	304	114	180	1.33	6.9	6.1	15.7	76	13.8	1.22	0.20	11.3	1.09	0.11	0.47	0.15
Cultiv.3 yr.	359	233	133	251	1.33	7.0	6.2	14.1	87	8.3	0.90	0.19	9.2	1.14	0.40	0.55	0.15
Cultiv.15 yr.	321	261	130	251	1.33	6.7	5.9	11.7	76	8.2	0.90	0.17	9.1	1.18	0.37	0.55	0.16
Manure	311	356	122	183	1.45	8.4	7.5	21.1	99	19.2	1.95	0.52	9.8	1.02	0.26	0.32	0.17

added as the first internal standard. The final organic phase was dried with dry air at 45 °C and finally dissolved in 300 μl ethyl acetate-hexane (1:1). Identification and quantification of amino sugars was conducted by capillary gas liquid chromatography (HP 5890 gas chromatography, HP Ultra 2 fused silica column) equipped with FID detector. 3-*O*-methylglucose was used as a recovery standard.

Statistics

Statistical analysis of the data was carried out in triplicate by one-way analysis of variance (ANOVA) using the software package Statistica 5.0 for Windows (1995). If the main effects were significant at $P < 0.05$, a post hoc separation of means was done by univariate least significance difference (LSD) test.

Results and discussion

Amino sugar pools

In this tropical soil, the content of hexosamines varied from 234 mg to 711 mg glucosamine kg^{-1} soil, 115 to 435 mg galactosamine kg^{-1} soil and 9 to 22 mg mannosamine kg^{-1} soil. The amount of muramic acid ranged from 8 mg to 37 mg kg^{-1} soil. Hence, the contribution of the amino sugars in the soil increased in the order: mannosamine < muramic acid < galactosamine < glucosamine. These results are in line with our results from the mountain soil of Khyrgyzia (Glaser et al. 2000) and with the results of Amelung (1997) and Zhang et al. (1998) for North American soils.

Clear-cutting and subsequent cultivation of the native tropical woodland resulted in a substantial depletion of both the hexosamine and muramic acid contents from the surface layers of this tropical soil (Fig. 1). When compared with the indigenous woodland, continuous cropping resulted in 68% and 72% reductions in the total amino sugar contents from the bulk soil of the 3- and 15-year cultivated fields, respectively. Moreover, a 39% decline in the amino sugar contents was observed in the bulk soil of the degraded woodland. Similar results were reported by Zhang et al. (1997, 1999) for arable North American soils. The depletion intensity of amino sugars due to cultivation in the semi-arid tropical agroecosystem of northern Tanzania, however,

was much higher than in the North American prairie. In addition to other differences of site attributes, the rapid decline in the amino sugar contents at our sites might be attributed to the accelerated decomposition of amino sugars and decreasing microbial biomass input under the relatively higher temperature of the semi-arid environment following clear-cutting and continuous cultivation.

In contrast, only a 20% decline was found from bulk soil of the fields where animal manure had been applied. The lower depletion of amino sugars from the fields where animal manure was applied could be due to the fact that manure provides an additional input of biologically processed organic compounds into the soil. In general, our results suggest that the rate of amino sugar production and mineralization was different under the different land-use systems in this semi-arid tropical agroecosystem. Moreover, the results from the 3- and 15-year cultivated fields indicate that most of the depletion of amino sugars from the two cultivated fields occurred in the first few years of cultivation.

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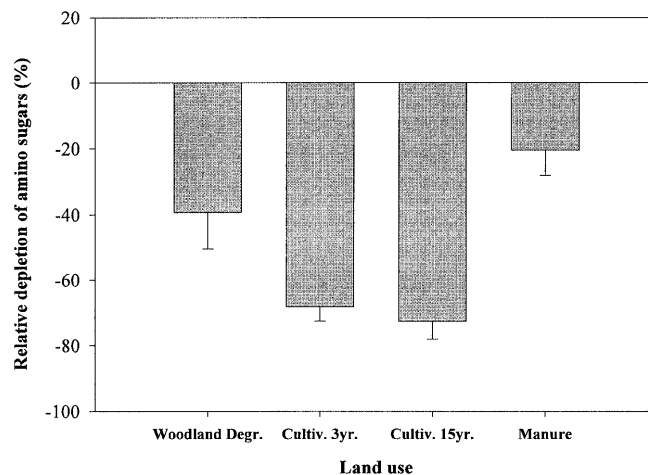


Fig. 1 Average depletion of amino sugar contents in bulk soils of the different land-use systems relative to the native tropical woodland in northern Tanzania. See Table 1 for explanations of abbreviations. *Error bars* indicate standard deviations of the means from the different land-use systems

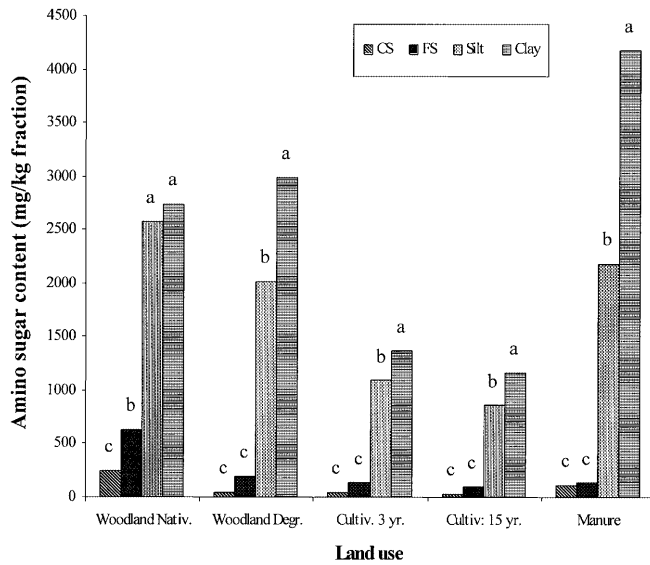


Fig. 2 Amino sugar contents (mg kg^{-1} fraction) in particle size separates of the different land-use systems in northern Tanzania. See Table 1 for explanations of abbreviations. Letters above the bars indicate significant differences between the means of different particle size separates within the same land-use system ($P < 0.05$)

Under all land-use systems, amino sugar contents in particle size separates (mg kg^{-1} fraction) increased in the order: coarse sand < fine sand < silt < clay (Fig. 2). The clay separate comprised the major part of the ami-

no sugar pools. This indicates that particle size fractionation yields characteristic pools of amino sugar accumulations.

Amino sugar concentrations in soil organic C

The concentration of total amino sugars in bulk soil decreased in the order: native tropical woodland > home-stead fields where animal manure was applied > degraded woodland > 3-year cultivated fields > 15-year cultivated fields (Table 2). These results show that the greatest decline in hexosamine and muramic acid concentrations occurred from the SOM of the cultivated fields. In the cultivated fields, microbial activity may increase due to improved aeration, thus increasing the rate of SOM breakdown. This could be accountable for the lower concentrations of amino sugars in the SOM of the cultivated fields. In addition, preferential degradation of amino sugars from the SOM over other organic substances, and lower production of amino sugars in cultivated fields, could also be attributed to the lower concentration of amino sugars in the cultivated fields (Zhang et al. 1997, 1999).

The difference in the concentrations of total amino sugars in SOM between the 3- and 15-year cultivated fields was not statistically significant ($P < 0.05$). This agrees with our study on SOM content of this soil,

Table 2 Amino sugar concentrations ($\text{g amino sugar kg}^{-1}$ SOC) of bulk soil and particle size separates of the different land-use systems in northern Tanzania. See Table 1 for abbreviations of land-use systems. Letters along the row indicate significant differ-

ences between the means of the different land use systems ($P < 0.05$). Total amino sugar Glucosamine + mannosamine + galactosamine + muramic acid

Separates	Amino sugars	Land use				
		Woodland Nativ.	Woodland Degr.	Cultiv. 3 yr.	Cultiv. 15 yr.	Manure
Bulk soil	Glucosamine	40.7a	31.2b	25.7c	23.1c	33.5b
	Mannosamine	1.18	0.79	1.12	1.04	0.69
	Galactosamine	26.2a	19.5b	12.3c	11.2c	20.0b
	Muramic acid	2.54a	1.14c	0.83d	0.72e	1.46b
	Total amino sugars	70.7a	52.6c	39.9d	36.1d	55.6b
Coarse sand	Glucosamine	27.3a	19.8b	13.9b	15.9b	17.0b
	Mannosamine	0.79a	0.76a	0.61a	0.53b	0.76a
	Galactosamine	19.7a	16.1b	9.0d	5.2e	13.1c
	Muramic acid	1.25a	0.80b	0.68b	0.74b	0.56b
	Total amino sugars	49.2a	37.4b	23.6d	22.4d	31.4c
Fine sand	Glucosamine	29.2a	22.6b	19.3c	16.2d	23.5b
	Mannosamine	0.89	0.67	0.81	0.56	0.97
	Galactosamine	22.0a	15.2b	13.1bc	9.3c	17.9b
	Muramic acid	1.35a	0.74c	0.85bc	0.61c	1.02b
	Total amino sugars	53.5a	39.2c	34.1d	26.7e	44.0b
Silt	Glucosamine	39.3a	30.7b	26.2c	20.5d	37.2a
	Mannosamine	1.29a	0.67c	0.63c	0.65c	0.86b
	Galactosamine	27.1a	20.0b	17.2c	13.1d	22.6b
	Muramic acid	2.97a	2.39a	1.02b	0.75b	2.35a
	Total amino sugars	70.7a	53.7c	45.1d	35.0e	63.0b
Clay	Glucosamine	65.0a	58.7b	53.0c	53.8bc	59.7a
	Mannosamine	1.37a	1.44a	1.00b	1.12a	1.46a
	Galactosamine	34.9a	29.6b	24.0c	25.0c	29.1b
	Muramic acid	7.06a	5.74a	4.80ab	4.01b	5.94a
	Total amino sugars	108.3a	95.5a	80.4b	83.7b	96.6a

where we found a similar amount of SOC and N depletions in bulk soil of the 3- and 15-year cultivated fields (Solomon et al. 2000). These results apparently support our previous suggestion that a rapid depletion of amino sugars occurred during the first 3 years of cultivation from this tropical soil. Bowman et al. (1990) also demonstrated that total SOC and N significantly declined during 60 years of cultivation of native North American soils, with half of the total loss recorded in the first 3 years of cultivation.

Application of manure effectively increased the total amino sugar concentrations of the SOM in the home-stead fields, indicating the positive effects of this agronomic measure for SOM quality in the this semi-arid tropical agroecosystem. An increase in C and N contents following manure application to sandy loam soils at Askov in Denmark was reported by Christensen (1988). Lehmann et al. (1997) also showed a 5- to 7-fold increase of organic C and N contents in fields which received goat manure compared with native savanna soils in northern Kenya.

Examination of particle size separates indicate that the concentration of hexosamines and muramic acid in SOM increased with decreasing diameter, the highest being found in the SOM bound in the clay separate. On average, the SOM associated with the clay separates contained 42% of the hexosamines and 60% of muramic acid, while the silt-bound SOM contained 25% of hexosamines and 21% of muramic acid. The SOM associated with the coarse size separates contained relatively lower concentrations of amino sugars (fine sand; 18% hexosamines, 10% muramic acids and coarse sand; 15% hexosamines, 9% muramic acid).

In order to compare the proportion of amino sugar concentrations associated with the SOM in different particle size separates within a soil, enrichment factors for the total amino sugar concentrations (E_{TAS}) = (g total amino sugar kg⁻¹ SOC in fraction)/(g total amino sugar kg⁻¹ SOC in bulk soil) were calculated. This excludes the effect of differential recoveries of hexosamine and muramic acid in soils from different sites. According to Table 3, the highest E_{TAS} values were obtained from clay separates, while the lowest E_{TAS} values were found in the coarse sand separates. In general,

clay- and silt-bound SOM was enriched in microbial-derived components in comparison with the SOM associated with coarse and fine sand separates. This is also in agreement with our previous study on the carbohydrate signature of this tropical soil where we found higher concentrations of microbial-derived sugars (hexose and deoxy sugars) in the clay and silt than in the fine and coarse sand separates of the soil under study (Solomon et al. 2000). Higher concentrations of microbial metabolites in the finer than in coarser particle size separates were also reported by Guggenberger et al. (1994) for Inceptisols in the pre-alpine regions of southern Germany and by Amelung (1997) and Zhang et al. (1997, 1998) for North American prairies.

The effects of clearing and cultivation on amino sugar concentrations was reflected in size separates, with largest decreases from the SOM associated with the coarse and fine sand separates. According to Christensen (1992), SOM associated with sand-size separates 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. In contrast, the losses due to cultivation from the silt- and clay-bound amino sugars of the degraded woodland and the cultivated fields were relatively small. The higher production of microbial metabolites (Guggenberger et al. 1995) and their intimate association and stabilization against mineralization in clay minerals could account for the enrichment of amino sugars in finer size separates of this soil. Generally, these results show the importance of organo-mineral associations in the stabilization of microbial-derived sugars in soils of the semi-arid tropics. When compared with the cultivated variants, incorporation of animal manure increased the concentrations of both hexosamine and muramic acid in SOM particularly associated with the finer size separates, thereby minimizing the negative impact of cultivation on amino sugars.

The depletion intensities of the four amino sugars as a result of cultivation of the native tropical woodland differed in this soil. According to Table 2, 53% and 57% of galactosamine and 67% and 71% of muramic acid were depleted from the 3- and 15-year cultivated fields, respectively. However, the proportion of glucosamine depleted from the 3- and 15-year cultivated fields was 37% and 43%, respectively, indicating that muramic acid and galactosamine declined more rapidly than glucosamine. The preferential depletions of muramic acid and galactosamine compared with glucosamine were also reported by Zhang et al. (1997) for the arable soils of North America. According to Zhang et al. (1997), the rapid depletion of these two amino sugars compared with glucosamine shows that muramic acid and galactosamine are less stable than glucosamine in cultivated soils. On the other hand, the production of these two amino sugars might also be inhibited in cultivated soil (Zhang et al. 1997).

Table 3 Enrichment of total amino sugar concentrations (E_{TAS}) of bulk soil and particle size separates of the different land-use systems in northern Tanzania. See Table 1 for abbreviations of land-use systems. *BS* Bulk soil, *CS* coarse sand, *FS* fine sand

Land use	E_{TAS}				
	BS	CS	FS	Silt	Clay
Woodland Nativ.	1.00	0.68	0.81	1.05	1.68
Woodland Degr.	1.00	0.71	0.71	1.07	1.80
Cultiv. 3 yr.	1.00	0.58	0.74	1.05	1.80
Cultiv. 15 yr.	1.00	0.71	0.74	1.03	2.09
Manure	1.00	0.61	0.78	1.16	1.85

Amino sugar patterns

Glucosamine is found in most fungal cell walls and in invertebrate exoskeletons such as chitin (Chantigny et al. 1997). Minor quantities of galactosamine have also been identified in the cell wall of *Ascomycetia* (Beever 1982), although Sowden and Ivarson (1974) demonstrated that very little galactosamine was synthesized during fungal-inoculated incubation. Nevertheless, the ratio of glucosamine to galactosamine (GlcN:GalN) has been successfully used to evaluate the relative contributions of fungi and bacteria to SOM turnover and accumulation (Sowden 1959; Kögel and Bochter 1985; Amelung 1997; Zhang et al. 1998; Amelung et al. 1999). Moreover, since muramic acid uniquely originates from bacteria (Zhang and Amelung 1996), the ratio of glucosamine to muramic acid (GlcN:MurA) was also used to evaluate the fate of bacterial-derived amino sugars in soil under temperate environments (Amelung 1997; Chantigny et al. 1997; Zhang et al. 1997, 1998).

The ratios of GlcN:GalN and GlcN:MurA varied markedly among particle size separates from this tropical soil (Table 4), showing that either the microbial origin or the stability of the different amino sugars was different between the size separates (Parsons 1981; Zhang et al. 1999).

The ratio of GlcN:GalN increased significantly from coarse sand to clay separates, while the highest ratios of GlcN:MurA were found in the coarse and fine sand separates and progressively decreased with decreasing particle size ($P < 0.05$, data not shown). Similar patterns of amino sugars in size separates were also reported by Amelung (1997) and Zhang et al. (1998) for North American soils. However, when compared with this tropical soil, the ratio of GlcN:GalN in the finer separates of the North American grassland soils remained stable. The decreasing ratio of GlcN:MurA from coarse sand to clay could be attributed to the enrichment of muramic acid as a result of increased stabilization in the clay and silt separates. However, bacterial-

derived galactosamine was enriched in the SOM associated with coarse sand rather than the silt and clay separates. According to Zhang et al. (1998), this might indicate that the major source of galactosamine is likely to be found in the first stage of SOM decomposition. Moreover, the contrasting tendencies of the two amino sugars might show that the dynamics of muramic acid is different from the dynamics of galactosamine.

The pattern of amino sugars in this soil were significantly influenced by the changes in land use. The ratio of GlcN:GalN increased significantly ($P < 0.05$) from 1.44 in the native woodland to 2.23 in 15-year cultivated fields, while the ratio of GlcN:MurA increased from 14.5 to 26.5 in the bulk soil of the native woodland and the 15-year cultivated fields, respectively (Table 4). These results may imply that cultivation of the native woodland led to the preferential depletion of the two bacterial-derived amino sugars (muramic acid and galactosamine) in comparison to fungal-derived glucosamine in this tropical soil.

Evaluation of size separates indicate that, with the exception of the clay-size separate, the ratios of GlcN:GalN and GlcN:MurA in the particle size separates of the cultivated fields were significantly higher ($P < 0.05$) than those in the native woodland. Zhang et al. (1999) also demonstrated that, regardless of the different degree of SOM alteration among the size separates, cultivation changes the relative distribution of fungal- and bacterial-derived sugars in soils. The lower ratios of both GlcN:MurA and GlcN:GalN in the finer size separates compared with the cultivated fields indicate that application of animal manure increased the amount of both bacterial-derived amino sugars.

Because of such significant changes of amino sugar patterns in the bulk soil and particle size separates, it is possible to suggest that both ratios of GlcN:GalN and GlcN:MurA can be used as sensitive tools to evaluate the impact of land-use on SOM dynamics in this tropical soil.

Table 4 Amino sugar ratios in bulk soil and particle size separates of the different land-use systems in northern Tanzania. See Table 1 for abbreviations of land use systems. *BS* Bulk soil, *CS* coarse sand, *FS* fine sand. *Different letters along the column indi-*

cate significant difference between the mean of different land-use systems ($P < 0.05$). GlcN:GalN Glucosamine:galactosamine ratio, *GlcN:MurA* glucosamine:muramic acid ratio

Amino sugar ratios	Land use	Separates				
		BS	CS	FS	Silt	Clay
GlcN:GalN	Woodland Nativ.	1.44b	1.02c	1.17d	1.48e	2.02
	Woodland Degr.	1.62b	1.36b	1.45c	1.66c	2.05
	Cultiv. 3 yr.	1.90a	1.78a	1.85a	1.95a	2.21
	Cultiv. 15 yr.	2.23a	1.70a	1.74b	1.89b	2.16
	Manure	1.52b	1.33b	1.43c	1.56d	2.02
GlcN:MurA	Woodland Nativ.	14.5b	17.4d	20.6b	9.1b	9.2
	Woodland Degr.	18.7b	24.6b	22.1b	12.8ab	10.1
	Cultiv. 3 yr.	25.4a	27.3a	24.3b	16.7a	11.1
	Cultiv. 15 yr.	26.5a	23.8c	29.9a	18.1a	10.6
	Manure	15.8b	27.5a	20.4b	9.7b	9.4

Conclusion

Clear-cutting and subsequent cultivation of the native tropical woodland resulted in a substantial depletion of both the hexosamine and muramic acid contents in the bulk soil and particle size separates of this tropical soil. The rapid decline of the microbial-derived sugar might be attributed to the accelerated decomposition of amino sugars and/or decreasing microbial biomass input under the semi-arid environment following clear-cutting and continuous cultivation.

The results from the 3- and 15-year cultivated fields indicate that most of the depletion of amino sugars occurred from the coarse and fine sand-associated SOM during the first 3 years of cultivation. The decline from the silt- and clay-bound amino sugars were relatively small, indicating the importance of organo-mineral associations in the stabilization of microbial-derived sugars in soils of the semi-arid tropics.

When compared with the cultivated variants, application of animal manure increased the concentrations of both hexosamine and muramic acid in SOM particularly associated with the finer size separates, thereby minimizing the negative impact of cultivation on amino sugars.

Continuous cultivation significantly increased the ratio of both glucosamine:galactosamine and glucosamine:muramic acid, suggesting that cultivation led to preferential depletion of the two bacterial-derived amino sugars (muramic acid and galactosamine) in comparison with fungal-derived glucosamine.

Based on our results, it is possible to conclude that both concentrations and ratios of amino sugars can be used as sensitive ecological indicators to evaluate the impact of land-use on SOM dynamics in tropical agroecosystems.

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