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Full Length Research Paper

Periodic flooding and land use effects on soil properties in Lake Victoria basin

Nancy Mungai W.[1]*, Njue A. M.[2], Abaya Samuel G.[3], Vuai Said A. H.[4] and Ibembe John D.[5]

[1]Department of Crops, Horticulture and Soils, Egerton University, P. O. Box 536, Njoro, Kenya.
[2]Department of Environmental Sciences, Egerton University, P. O. Box 536, Njoro, Kenya.
[3]Community Livelihood Development Forum, P. O. Box 3444, Kisumu, Kenya.
[4]Department of Physical Sciences. The University of Dodoma, P. O. Box 259, Dodoma, Tanzania.
[5]Busoga University, P. O. Box 154, Iganga, Uganda.

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Frequent periodic flooding and land use changes taking place in the Lake Victoria basin (LVB) in east Africa may cause soil deterioration and further exacerbating food insecurity. Surface (0 to 20 cm) soil samples were collected at three locations along Sondu Miriu (Kenya) and Simiyu-Duma (Tanzania) rivers. Samples were collected from fields that were periodically flooded (1-28 d) and those that never flood, either under grass or crops. Samples were analysed for soil texture, organic carbon (OC), total nitrogen (TN), pH, extractable phosphorus (P), exchangeable potassium (K) and β-glucosidase activities. β-glucosidase activities, clay and P contents were higher in some of the soils that flood, while OC, exchangeable K and sand contents were lower at $P< 0.05$ in flooded soils. Observed differences account for 11% of comparisons in the two river basins. Soils under grass had higher β-glucosidase activities and silt content but lower sand content than cultivated soils in 6% of samples in the two basins. However, conversion of natural ecosystems to grassland or cropped lands resulted in a 17 to 113% reduction in OC, TN, and exchangeable K in Sondu, and a 129% decline in TN in Simiyu. Soil properties exhibited clear but different patterns from upstream to downstream in the two basins. OC, TN, clay and β-glucosidase activities were higher in Sondu upstream, while OC, TN, extractable P and exchangeable K were lower in Simiyu upstream. Observed difference across each basin underscore the importance of inherent soil characteristics in influencing soil properties compared to short-term flooding or short duration changes in land use.

Key words: Flooding, land use, soil properties, soil deterioration, Lake Victoria basin.

INTRODUCTION

Some of the chemical changes that can take place in flooded soils include variations in soil pH, electrical conductivity, redox potential, denitrification activities and production of organic acids (Unger et al., 2009; Imbellone et al*.,* 2001). Such chemical changes may over time alter soil properties including soil nutrient availability, enzyme activities and organic matter dynamics. However, variable results have been reported on the effects of flooding on soil properties. Soil nitrate N (NO_3-N), for example, decreased under 5-week but increased under 3-week inundation. The decrease in NO_3-N was four times greater for stagnant than for flowing water at 5-week flooding (Unger et al*.,* 2009). These authors further reported no changes in soil pH, total nitrogen (TN), organic carbon (OC) and ammonium nitrogen (NH_4-N) where the water was allowed to flow or remain stagnant

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*Corresponding author. E-mail: mungain03@yahoo.com. Tel: 254-720-390893.

Abbreviations: OC, Organic carbon; **TN,** total nitrogen; **P,** phosphorus; **K,** potassium; **NO_3-N,** soil nitrate N; **NH_4-N,** ammonium nitrogen; **FDA,** fluorescein diacetate; **LVB,** Lake Victoria basin; **$NaHCO_3$,** sodium bicarbonate; **EDTA,** ethylenediaminetetraacetic acid; **H_2SO_4,** sulfuric acid; **$CaCl_2$,** calcium chloride; **SAS,** statistical analysis software; **Ca,** calcium; **Mg,** magnesium.

for 3- 5 weeks. Imbellone et al. (2001) observed that reduction conditions did not persist long enough to substantially influence soil properties under the periodic flooding of three months (during rice production) followed by three years of dry farming.

Soil enzyme activities can be used as a quick indicator of changes in soil quality (Mungai et al., 2005). β-glucosidase, for example is the most abundant of the enzymes involved in cellulose degradation and thus plays an important role in carbon (C) cycle. Changes in β-glucosidase activity can provide insights into changes in OC dynamics because of the positive correlations between β-glucosidase and OC for aerobic soils (Mungai et al*.,* 2005) and anaerobic soils (Wang and Lu, 2006). Water logging has been shown to decrease fluorescein diacetate (FDA) and β-glucosidase activities under laboratory conditions, and this effect was enhanced with increasing water logging time (Wang and Lu, 2006). Pulford and Tabatabai (1988**)** showed that short-term water logging (7 days) inhibited the activities of β-glucosidase and other enzymes in different soils, and that the inhibition effect was dependent on soil type. In contrast, β-glucosidase activities and those of other C transforming enzymes were enhanced by flooding while phosphatase activity showed no response to flooding (Wilson et al*.,* 2010).

There is a growing need for information on soil quality following rapid land use changes taking place in the Lake Victoria basin (LVB). Some information currently exists regarding the impact of various management practices on soil properties in diverse regions of east Africa. Tukahirwa (2003) reported 38 to 110% reduction in exchangeable calcium (Ca) and magnesium (Mg), and OC in cultivated soils in relation to undisturbed woodlands in south western Uganda. In the same study, extractable phosphorus (P) accumulated in cultivated and fallow lands relative to undisturbed woodlands, due to repeated P applications and immobility of P. Reductions in total C (-56%) and TN (-51%) were observed in bulk soils of cultivated fields in northern Tanzania compared to native woodland (Solomon et al*.,* 2000). Soil erosion by water is a big challenge in the LVB where losses of up to 93 t ha^{-1} yr^{-1} have been reported for crop land (Lufafa et al*.,* 2003). The high soil losses are associated with heavy rainfall in upper catchments that lead to cyclic flooding in the lower catchments of LVB. Documentation of the effect of periodic flooding in different land uses on soil properties is important to assess long term land productivity in the LVB and to provide empirical evidence for preventive interventions for annual inundation. The objectives of this work were: one, to assess the effect of periodic flooding on soil properties in the two basins; and two, to determine the effect of different land uses on soil properties in the two basins. Establishing the effect of flooding on enzyme activities may provide clues to biochemical processes within the soil that may result in important changes in soil properties.

METHODOLOGY

Study area

Sondu-Miriu river basin (referred as Sondu basin hereafter) has a catchment area of approximately 3, 487 km^2. Upstream Sondu basin receives more than 2,000 mm of rainfall annually, with peaks during the long rains in March-May and the short rains in September-October. The heavy rainfall results in flooding twice a year to an average depth of 0.3-0.6 m. The Simiyu–Duma (referred to as Simiyu hereafter) basin is situated in Magu district within Mwanza region in Tanzania, and comprises a catchment area of 3,300 hectares of wetlands. Simiyu basin has two rainy seasons; the short rains occur in November and December and long rains in March to May resulting in a total annual rainfall of 700 to 1000 mm (Rwetabula and de Smedt, 2005). Sondu and Simiyu rivers drain into Lake Victoria and they both have a direct influence on the sediment and nutrient load into the lake hence the selection of both sites.

Soil sampling

Soil sampling was done in November 2007 and March 2008 at Sondu and Simiyu, respectively. Several sites were selected along the Sondu and Simiyu rivers to represent upstream, midstream and downstream locations (Figure 1). At each location, soils were sampled from areas that flood annually (following interviews with landowners) and from those that do not flood. In Sondu, 15 samples were collected each at upper, mid and downstream to give a total of 45 samples, out of which 17 samples were collected in soils that flood (14 grass, 3 cropped) and 28 samples in soils that do not flood (15 grass, 13 cropped). Most of the soils that flood were under grass with only a few parcels under crops in Sondu. In Simiyu a total of 41 samples were collected, 12, 16 and 13 at upper, mid and downstream, respectively. Twenty two samples were collected from soils that flood and 19 from those that do not flood, half of each under grass (20) and the other half under crop (21). Flooded soils were usually closest to the river as a result of river flooding which usually occurs during the main rainy season. Under each flood condition, samples were collected from cropped areas (for at least three years) and areas under grass (grass was mostly unimproved and occasionally grazed). 6 soil cores were collected at each flood-land use site at 0-20 cm depth using a soil auger.

Soils were also collected at natural undisturbed sites. In Sondu, sampling was done at Mau Forest in Kericho, an area dominated by indigenous trees *Croton macrostachyus* and *Newtonia hilderbranditii*. At Simiyu, soil samples were collected at Mwakinyama Game Reserve, Maswa in which the dominant species included *Dispyros fischeri*, *Boscia mossambicensis*, *Markhamia obtusifolia* and *Grewia bicolor*. Soil samples were mixed thoroughly to make one composite sample. The samples were then transported to the laboratory for analysis of β-glucosidase activities, soil texture, pH, TN, OC, extractable P and exchangeable potassium (K). After air drying, and sieving through a 2 mm sieve, samples were extracted with 0.5 M sodium bicarbonate ($NaHCO_3$) + 0.01 M ethylene diamine tetraacetic acid (EDTA) (pH 8.5, modified Olsen) using a 1:10 soil/solution ratio and analyzed by flame photometer for exchangeable K and calorimetrically (molybdenum blue) for extractable P. OC was determined calorimetrically after sulphuric acid (H_2SO_4) – potassium dichromate oxidation at 150℃ for 30 min. TN was determined by Kjeldahl digestion (Okalebo et al*.,* 2002) with H_2SO_4 and selenium as a catalyst. Soil pH (1:1) in water and calcium chloride ($CaCl_2$) was also determined. Soil texture was determined by hydrometer method (Okalebo et al*.,* 2002). β-glucosidase activities were analyzed using the method of Dick et al. (1996),which is based on calorimetric determination of

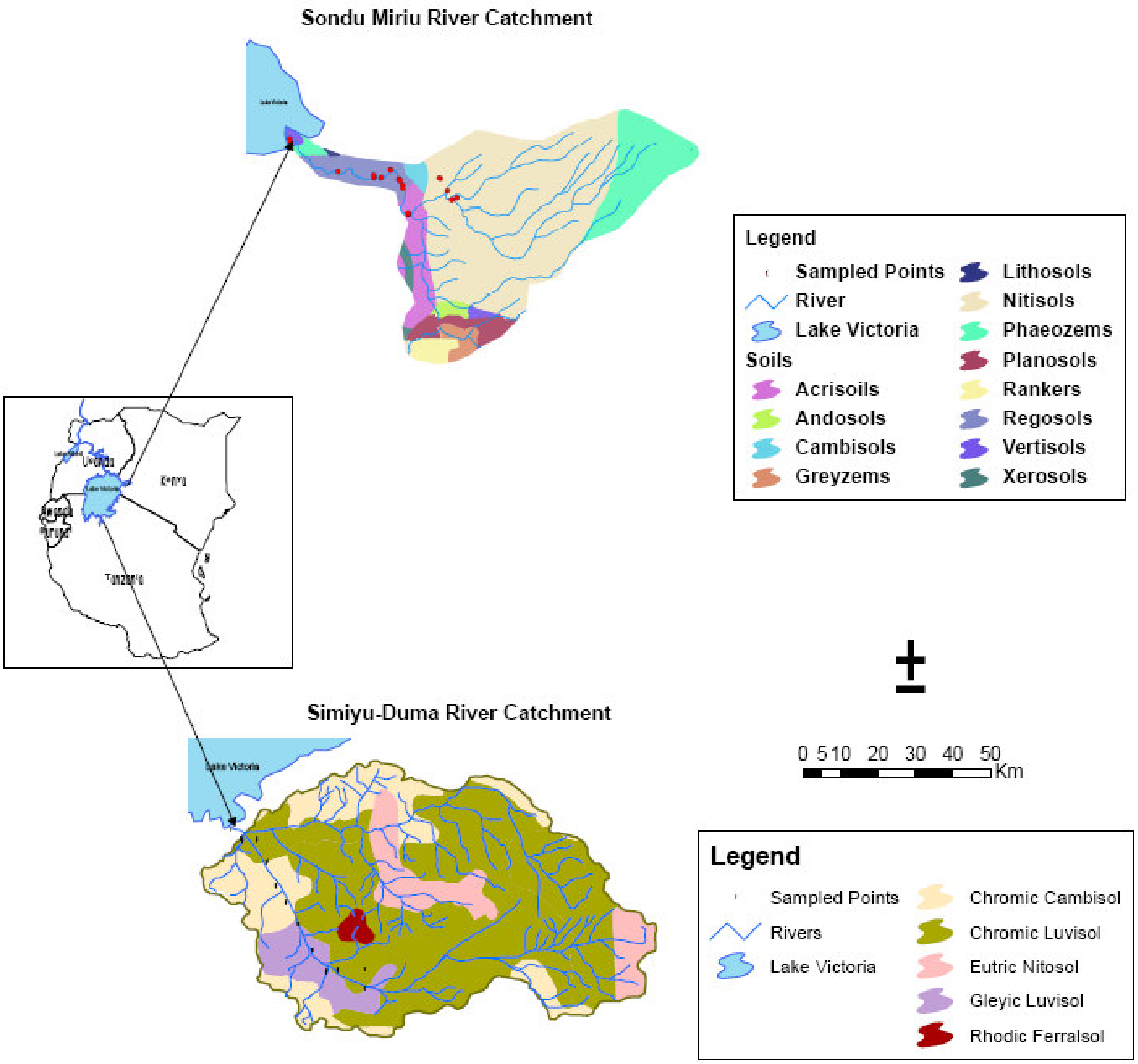

Figure 1. The Sondu-Miriu and Simiyu-Duma basins showing sampling points and the major soil types.

ρ-nitrophenol released by β-glucosidase when soil is incubated with a buffered (pH 6.0) ρ-nitrophenol-β-D-glycopyranoside as the substrate.

A deterioration index was computed for upper catchment sites (those closest to the natural sites and under the same soil order) as shown in formula (1):

$$\text{Deterioration index (\%)} = \{(\text{land use value} - \text{natural site value}) / \text{land use value}\} \times 100 \tag{1}$$

Deterioration index is the difference between mean values of individual soil properties under crop and grass compared to values of soil properties under natural conditions expressed as a percentage of mean value of individual properties (Islam and Weil, 2000). Since soil pH is a logarithmic scale, a deterioration index was not computed, further, the criteria of “more is better” may not hold true for pH. A negative index value indicates that the soil parameter is lower than that of the natural site, while a positive value would indicate the reverse. The actual value of index denotes the degree of change in a particular parameter, in either direction, where a large percentage indicates a greater change.

Data analysis

Soil data was tested for normality using the Shapiro-Wilk test in statistical analysis software (SAS), a more reliable test when N < 50. Most of the parameters in Simiyu basin were normally distributed except P while all the parameters in Sondu basin were not normally distributed. Non- parametric Kruskal-Wallis method was therefore used to detect statistically significant differences among land uses, flooding conditions and locations within each basin. Spearman linear correlation analysis was performed to determine associations among different soil properties.

RESULTS

Flooding and land use effects on soil properties

Soils in lower catchments and those adjacent to Sondu and Simiyu rivers banks experience annual inundation during the long rains in March to May of each year. Soil

Table 1. Flooding effects on soil properties (0-20 cm) along Sondu-Miriu basin.

Parameter	Flooding	Upstream	Midstream	Downstream
Organic Carbon (%)	Floods	2.3(0.1) [a]	1.6(0.1)	1.4(0.3)
	N- Floods	2.5(0.4)	1.7(0.3)	1.2(0.3)
Total Nitrogen (%)	Floods	0.34(0.01)	0.20(0.03	0.14(0.03)
	N- Floods	0.37(0.01)	0.22(0.06)	0.12(0.03)
Extractable P (mg kg^{-1})	Floods	6.0(4) [†]	6.9(6)	5.7(4)
	N- Floods	3.1(2) [†]	7.3(6)	5.4(7)
Extractable K (mg kg^{-1})	Floods	134(76) [†]	250(136)	207(87)
	N- Floods	332(262) [†]	137(71)	218(95)
pH (CaCl$_2$)	Floods	4.0(0.4) [†]	4.4(0.1)	4.6(0.7)
	N- Floods	4.4(0.4) [†]	4.4(0.4)	4.6(0.2)
β- Glucosidase(µgg^{-1} h^{-1})	Floods	165(100)	71(29)	107(79)*
	N-Floods	245(106)	195(136)	53(37)*
Sand (%)	Floods	32(14)	40(9)	43(11)
	N-Floods	29(8)	37(5)	53(15)
Clay (%)	Floods	46(9)	36(7)	35(6)
	N-Floods	48(8)	40(7)	28(9)
Silt (%)	Floods	21(9)	24(4)	21(6)
	N- Floods	23(6)	23(5)	19(9)

N-floods = never floods, [a] numbers in parentheses represent one standard deviation, * shows significant difference at P<0.05, [†] shows significant difference at P< 0.1.

properties under areas that flood versus those never flood in Sondu and Simiyu river basins are shown in Tables 1 and 2, respectively. Out of the 54 pairs compared across the two basins 10 showed significant differences. β-glucosidase activities were higher under flooded conditions in downstream Sondu basin (107 compared to 53 µg g^{-1}) at p< 0.05. In upstream Sondu, exchangeable K and pH were also higher for flooded soils (331 compared to 134 mg kg^{-1} and 4.4 compared to 4.0, respectively) while P was lower (3.1 compared to 6.0 mg kg^{-1}), all compared at p< 0.1 (Table 1). In downstream Simiyu, clay content was higher in flooded soils (57 compared to 24 %), while sand and K levels were higher for non-flooded soils (61 compared to 22% and 304 compared to 176 mg kg^{-1}, respectively). In midstream and upstream Simiyu basin, P was higher for soils that periodically flood (12.2 compared to 8.0 and 10.9 compared to 4.2 mg kg^{-1}) (Table 2). OC was 76% higher for soils that do not flood in up-stream Simiyu (0.43 compared to 0.76%) at p< 0.05.

Agricultural land use and management can have varying effects on soil properties based on the intensity and longevity of each management activity or land use. Of the 54 pair comparisons for soils under cultivation versus those under grass, 3 pairs indicate significant differences (Tables 3 and 4). Soils under grass had more silt (28 vs. 20%) and less sand (34 vs. 41%) than cultivated soils in midstream Sondu (Table 3). β-glucosidase activities were higher for soils under grass (163 µg g^{-1}) than cultivated (83 µg g^{-1} soil) soils in downstream Simiyu (Table 4).

Significant differences in most of the soil properties were observed from up- to down-stream in both basins. Upstream soils had higher OC, TN and β-glucosidase activities than downstream soils in Sondu (Figure 2a, c and e), while the contrast was generally true for Simiyu (Figure 2b, d, and f). Clay content followed similar contrasting trends as OC in Sondu (Figure 3a) and Simiyu (Figure 3b). Soil pH was slightly higher in downstream soils in Sondu (Figure 3c) but lower in downstream Simiyu (Figure 3d). Extractable P was comparable across Sondu basin (Figure 3e), but was

Table 2. Flooding effects on soil properties (0 to 20 cm) along Simiyu-Duma basin.

Parameter	Flooding	Upstream	Midstream	Downstream
Organic Carbon (%)	Floods	0.4(0.2) *	0.5(0.2)	1.3(0.2)
	N- Floods	0.8(0.4) *	0.5(0.2)	0.7(0.3)
Total Nitrogen (%)	Floods	0.06(0.03)	0.05(0.03)	0.11(0.04
	N- Floods	0.08(0.04)	0.06(0.02)	0.07(0.03
Extractable P (mg kg^{-1})	Floods	10.9(5) **	12.2(7)*	19.2(11)
	N- Floods	4.2(1) **	8.0(10)*	39.6(36)
Extractable K (mg kg^{-1})	Floods	135(79)	205(117)	175(102) *
	N- Floods	65(31)	204(69)	303(92) *
pH (CaCl$_2$)	Floods	8.7(0.1)	8.2(0.1)*	7.8(0.3)
	N- Floods	8.5(0.2)	7.5(0.1)*	7.7(0.1)
β gluc (µg g^{-1} h^{-1})	Floods	92(59)	138(150)	122(78)
	N- Floods	169(125)	145(113)	117(25)
Sand (%)	Floods	64(19)	64(16)	22(3)**
	N-Floods	58(8)	69(16)	61(21)**
Silt (%)	Floods	16(10)	14(5)	21(11)
	N- Floods	14(2)	11(4)	15(6)
Clay (%)	Floods	20(9)	22(13)	57(11)**
	N- Floods	27(7)	20(7)	24(16) **

N-flood = never floods, [a] numbers in parentheses represent one standard deviation, ** shows significant difference at $P < 0.01$, * shows significant difference at $P < 0.05$.

Table 3. Land use effects on soil properties (0 to 20 cm) along Sondu-Miriu basin.

Parameter	Land use	Upstream	Midstream	Downstream
Organic Carbon (%)	Cropped	2.5(0.5)[a]	1.6(0.3)	1.3(0.3)
	Grass	2.4(0.3)	1.7(2.5)	1.4(0.3)
Total Nitrogen (%)	Cropped	0.41(0.16)	0.20(0.06)	0.13(0.01)
	Grass	0.34(0.11)	0.22(0.06)	0.13(0.04)
Extractable P (mg kg^{-1})	Cropped	2.6(1) *	7.5(4)	4.5(3)
	Grass	5.1(3) *	6.9(8)	6.2(7)
Extractable K (mg kg^{-1})	Cropped	249(194)	145(66)	207(78)
	Grass	254(251)	192(132)	117(99)
pH (CaCl$_2$)	Cropped	4.4(0.3)	4.2(0.4)	4.5(0.7)
	Grass	4.2(0.5)	4.5(0.3)	4.8(0.1)
β gluc (µg /g soil h^{-1})	Cropped	211(116)	126(109)	67(77)
	Grass	215(116)	204(145)	85(41)
Sand (%)	Cropped	31(9)	41(6.9)*	46(16)
	Grass	29(4)	33(4)*	50(9)

Table 3. Contd.

Clay (%)	Cropped	50(5)	39(5)	31(7)
	Grass	46(3)	39(5)	31(9)
Silt (%)	Cropped	19(2)	20(5)*	23(8)
	Grass	24(6)	28(6)*	18(7)

Table 4. Land use effects on soil properties (0 to 20 cm) along Simiyu-Duma basin.

Parameter	Land use	Upstream	Midstream	Downstream
Organic Carbon (%)	Cropped	0.7(0.5) [a]	0.5(0.2)	1.2(0.4)
	Grass	0.5(0.4)	0.5(0.2)	1.1(0.5)
Total Nitrogen (%)	Cropped	0.07(0.03)	0.06(0.03)	0.10(0.4)
	Grass	0.07(0.04)	0.06(0.02)	0.09(0.03)
Extractable P(mg kg^{-1})	Cropped	8.3(5)	8.9(7)	33.7(33)
	Grass	6.8(4)	11.3(10)	19.3(5)
Extractable K (mg kg^{-1})	Cropped	76(38)	200(110)	215(109)
	Grass	124(86)	209(79)	234(130)
pH ($CaCl_2$)	Cropped	8.6(0.1)	8.0(0.3)	7.7(0.4)
	Grass	8.8(0.2)	7.8(0.2)	7.9(0.4)
β glucosidase(µg g^{-1} h^{-1})	Cropped	122(112)	162(98)	83(40)**
	Grass	139(100)	122(147)	163(42)**
Sand (%)	Cropped	64(16)	63(16)	34(23)
	Grass	58(14)	70(9)	40(25)
Silt (%)	Cropped	14(7)	13(5)	19(9)
	Grass	17(8)	12(43)	19(11)
Clay (%)	Cropped	22(10)	24(13)	47(22)
	Grass	25(8)	18(6)	41(20)

higher in downstream Simiyu (Figure 3f). The differences observed within and between basins underscore inherent differences in major soil groupings. Figure 1 shows the major soil groups in the two basins, where nitisols, regosols and vertisols/phaeozems dominate Sondu up-, mid- and down-stream soils, respectively. In Simiyu, soils were collected from chromic cambisols, chromic Luvisols and gleyic Luvisols (Figure. 1)

Soil deterioration (change) index

Soil deterioration (change) index was computed for Sondu and Simiyu upper catchments as shown in Tables 3 and 4, respectively. In Sondu, changing land use from forest to either grass or cultivation of crops lead to declining levels of soil chemical properties ranging from -13 to -113% (Table 5). The largest decline was in total OC, followed by TN and extractable K. Soil pH also declined over time in grassland and cultivated soils. However extractable P was higher in grassland than in forested soil (Table 5).

In Simiyu, a decline of 129% was observed in TN in both grassland and cropped soils, while total OC remained about the same in grassland and improved marginally in cultivated soil (Table 6). Extractable P and

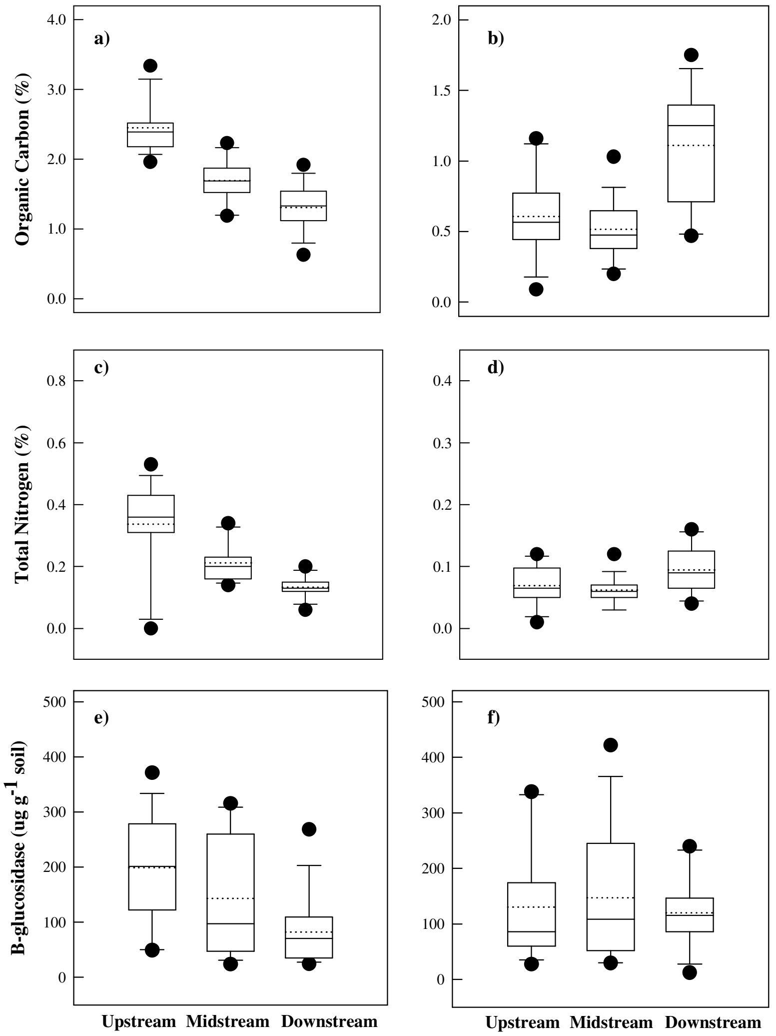

Figure 2. Variations in organic C (a and b), total N (c, d) and β- glucosidase (e and f) at Sondu and Simiyu basins, respectively, averaged across land uses and flooding regimes. **(**The lower box boundary indicates the 25th percentile, the solid line within the box marks the median, and the upper boundary of the box indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles. The mean is shown by the dotted line and outlying points by circles).

K increased over time under grass and cultivation in Simiyu basin (Table 6).

OC and TN were positively and significantly correlated to each other and to clay, silt and β-glucosidase (Table 7). Sand was negatively correlated to OC, TN, clay, silt and β-glucosidase. Correlation coefficients for β-glucosidase were generally low for combined data because these correlations were significant and higher for Sondu basin but not in Simiyu. In Sondu, β-glucosidase was positively correlated to C (r=0.61, p<0.0001), N (r=0.57, p< 0.0001) and clay (r=0.42, p=0.0045) and negatively correlated to sand (r=-0.36, p=0.015). All other correlations were significant in both basins.

DISCUSSION

Soil properties in periodically flooded soils

Periodic flooding is common in lower zones of the Lake Victoria basin. Soils are inundated for different periods depending on rainfall amount and soil type but usually for about1-28 d per year. Observed differences where OC was higher in flooded soils may have resulted from pockets of soil which were under anoxic conditions for long duration resulting in reduced microbial activity and hence an accumulation of C. Chacon et al. (2005) reported higher OC for zones inundated for more than 5 months per year compared to those that were inundated

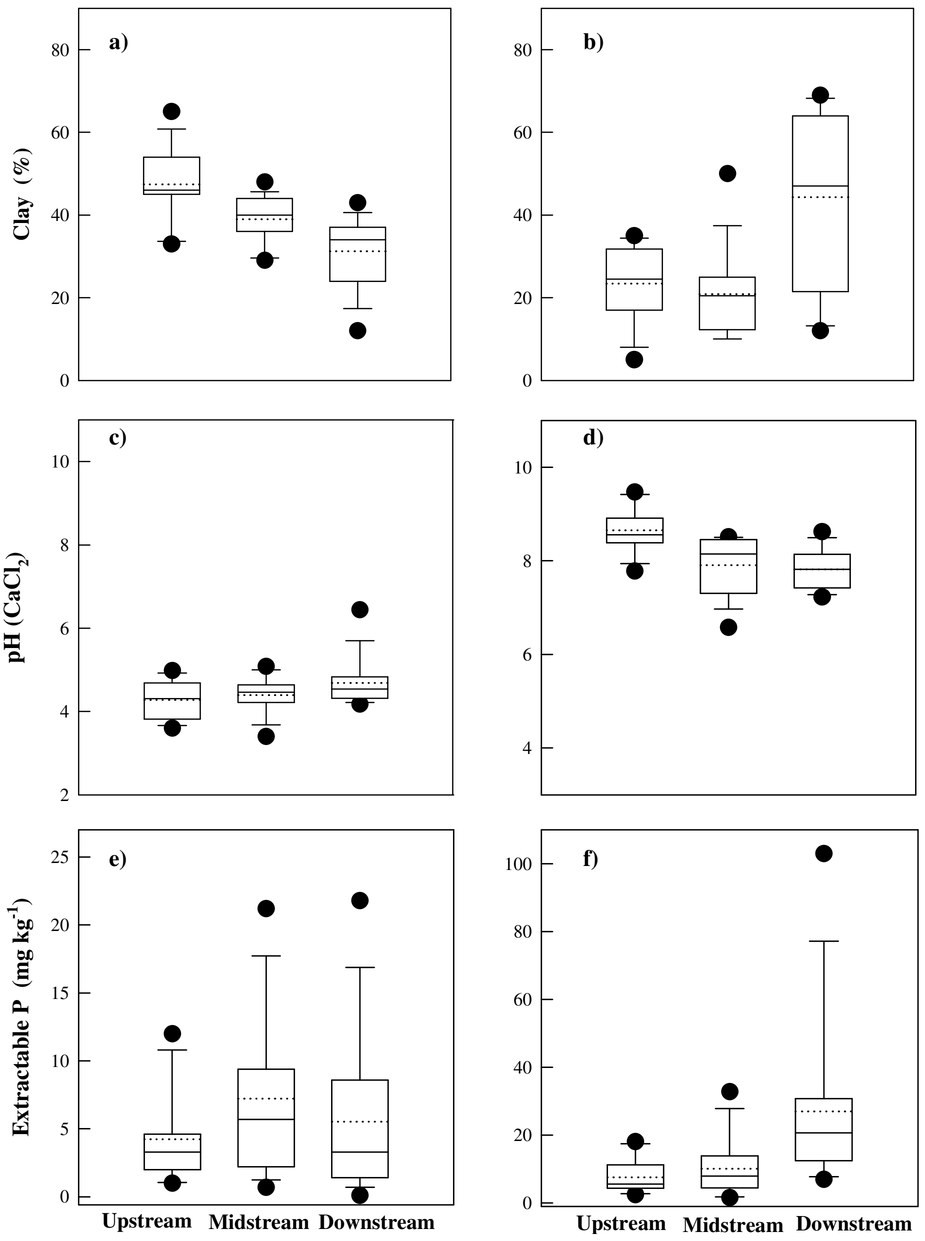

Figure 3. Percent clay (a and b), pH (CaCl$_2$) (c, d) and extractable P (e and f) at Sondu and Simiyu basins, respectively, averaged across land uses and flooding regimes. (The lower box boundary indicates the 25th percentile, the solid line within the box marks the median, and the upper boundary of the box indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles. The mean is shown by the dotted line and outlying points by circles).

Table 5. Soil properties (0-20 cm) of reference site (Mau Forest-Kericho) and deterioration/ change index for Sondu basin upper catchment.

Soil property	Natural site	Grassland	Cropped	Deterioration/ change Index (%)	
				Grassland	Cropped
Total org. C (%)	5.1	2.4	2.5	-113	-104
Total N (%)	0.6	0.34	0.33	-76	-82
Extr. P (mg kg^{-1})	4.0	5.4	2.6	26	-54
Extr. K (mg kg^{-1})	480	254	250	-89	-92

Table 6. Soil properties (0 to 20 cm) of reference site (Mwakinyama Game Reserve-Maswa) and deterioration/change index for Simiyu upper catchment.

Soil property	Natural site	Grassland	Cropped	Deterioration/ change Index (%)	
				Grassland	Cropped
Total org. C (%)	0.6	0.6	0.7	0	14
Total N (%)	0.16	0.07	0.07	-129	-129
Extr. P (mg kg^{-1})	1.5	7	8	79	81
Extr. K (mg kg^{-1})	59	117	78	50	24

Table 7. Spearman correlation coefficients (r) between soil properties for Sondu and Simiyu combined data.

	Carbon	Nitrogen	Sand	Clay	Silt
Carbon	1				
Nitrogen	0.92***	1			
Sand	-0.76***	-0.67***	1		
Clay	0.76***	0.68***	-0.93***	1	
Silt	0.57***	0.57***	-0.71***	0.49***	1
β- glucosidase	0.30 **	0.27*	-0.23*	0.26*	0.15

*, ** and *** represent significance at α=0.05, 0.01 and 0.001, respectively.

for 2 months. Zones inundated for longer periods also had higher clay and lower sand contents, as observed in this study. Generally soils with a sandy texture will allow better flow of water minimizing durations under water logged conditions as opposed to clayey textured soils.

Flooding did not influence soil properties in 92% of the samples in this study. Inundation of a mollic fluvent (mollic Fluvisols in FAO classification) for 3-5weeks under flowing or stagnant water resulted in no changes in soil pH, TN, OC and NH_4–N (Unger et al*.,* 2009). Similarly, Imbellone et al. (2001) observed that reducing conditions do not persist long enough to substantially influence soil properties in a vertic Argiudoll (luvic Phaeozem) under periodic flooding of three months (during rice production) followed by three years of dry farming. Changes in soil properties are more distinct under prolonged and recurrent water logging conditions of more than 2 months (Chacon et al., 2005). Our study looked at short-term flooding effects that occur annually. It was hypothesized that short- term flooding would influence microbial community structure and functioning, which may in turn influence other soil properties. β-glucosidase activities were higher under flooded soils in downstream Sondu basin. Wilson et al. (2010) observed that short-term (0-24 d) flooding induced significant changes in the microbial community structure and increased soil respiration and β-glucosidase (among other enzymes) activities. These authors further noted that shifts occurred in carbon fractions after flooding where labile carbon fractions increased, with no changes in total organic carbon. Most agricultural flooding experiments use short duration of between 8-28 days (Striker, 2008). Our study used on-farm sites that were inundated for periods within this range.

Land use effects on soil properties

In our study, differences in soil properties between grasslands and cultivated fields were minimal, possibly because the grass was unimproved and not intensively managed. Wilson et al. (2008) reported similar results, where minimal differences were observed between cultivated fields and unimproved grasslands. OC and β-glucosidase activities have been shown to be higher in well managed pastures (Martinez et al., 2007) and under improved fallows (Bilgo et al., 2007) compared to cultivated fields. Such results are associated with increased organic inputs through sloughed grass roots, exudates and litter. Additionally, lack of differences between cultivated lands and those under grass may be attributed to the reduced time under grass in the two basins. Land pressure in the two basins does not allow long duration pastures, and households are only able to rear few animals.

Conversion of native/natural ecosystems to agricultural practices usually reduces soil organic matter due to frequent tillage and accelerated mineralization (Solomon et al., 2000; Islam and Weil, 2000). The reduction observed in this study for OC and TN in Sondu and TN in Simiyu following cultivation was expected. Soil OC and TN decreased by 125 and 103%, respectively, following conversion of native woodlands to agriculture in Northern Tanzania (computed from Solomon et al., 2000). Wilson et al. (2008) also observed similar declines in OC and N in Australia. However, OC in Simiyu remained relatively unchanged. Use of organic soil amendments in cultivated lands (Monkiedje et al., 2006; Solomon et al., 2000) and well managed grasslands (Pouyat et al., 2007) can maintain or result in higher soil OC levels than in natural undisturbed sites. Solomon et al. (2000) reported no changes in OC in home-fields that received regular manure application in comparison to native woodlands in northern Tanzania. Soil samples in Simiyu were collected in outfields where off-season grazing was practiced which may explain the comparable OC content with native woodland. In addition, shifting cultivation is still a common practice in Simiyu basin.

Differences in soil properties along two river basins

Spatial variation of soil properties can be the product of soil forming factors acting over a continuum of space and time or of imposed soil management practices, such as cropping system, tillage and fertilizer or manure application. This study observed major differences in soil properties across the basins but no land use or flooding effects. The decreasing trends in soil properties from upstream to downstream observed in Sondu basin may be related to soil pedogenic differences. Topographic variability, developing over pedogenic time scales, has been shown to have the greatest effect on OC and TN, while grazing and individual plant species only had minor influences (Burke et al., 1999). Soils in upstream Sondu were predominantly Nitisols (kandic groups of Alfisols and Ultisols in USDA classification). In general, Nitisols are considered fertile soils, with high clay content, moderate CEC but low level of available phosphorus (Driessen et al., 2001). Our results show upstream Sondu soils had OC, TN and extractable P of 2.5%, 0.35% and 5 mg kg^{-1}, respectively, fitting within the general description of Nitisols. Soils with an OC and TN greater than 1.5 and 0.12%, respectively are considered to be of moderate fertility (Okalebo et al., 2002), while an extractable P content of > 10 mg kg^{-1} is required for crop production. Regosols (Entisols) were dominant in midstream of Sondu basin. Surface horizons of Regosols tend to be thin and low in organic matter (Driessent et al., 2001). Downstream soils were predominantly Phaezoms (udolls), which are usually of high fertility but may exhibit variable chemical characteristics due to uneven sedimentation from upstream Sondu basin. In Simiyu, downstream soils which were dominantly chromic Luvisols (Alfisols), had higher OC, TN, clay and extractable P than midstream chromic Cambisols (Inceptisols) and upstream (gleyic Luvisols) soils. The chemical properties of Luvisols vary with parent material and pedogenetic history (Driessen et al., 2001). Downstream soils had higher clay content than mid- and up-stream soils. Soils that are rich in clay are also associated with high OC and N (Chacon et al., 2005). Simiyu basin soils were generally low in OC (< 1.0%) and TN (< 0.1%), and high in sand content.

Soil OC and TN are usually positively correlated, form the main components of organic matter and are mostly associated with fine soil particles particularly clay (Solomon et al., 2000). Mungai et al. (2005) and Wang and Lu (2006) reported positive correlation between β-glucosidase and OC. β-glucosidase plays an important role in the C cycle where it catalyzes the conversion of cellulose, the largest source of C, in soil. Such correlation can be used to develop rapid and easily performed analysis for assessing soil change.

Conclusions

Our results suggest that periodic flooding and selected land uses in LVB did not affect soil properties for samples taken during non-flood conditions. As prevalent under small-holder farming systems, land uses combined as cropped or grassland differed in terms of duration, plant species and cultural and nutrient management, factors that can confound the effect of land use. However, conversion of natural ecosystems to grassland or cropped lands resulted in a 13 to 113% reduction in total OC, TN, extractable P, and K in Sondu, and a 129% decline in TN in Simiyu.

OC, TN, β-glucosidase and clay content decreased from upstream to downstream in Sondu basin, while the contrast was generally true in Simiyu basin. Results observed in this study indicate that pedo-genetic differences exert greater influence on soil properties than short-term changes in land use and periodic flooding, and should be considered in regional agricultural development programs. In addition, a clustering approach based on history of land use management can be used in future to better assess land use effects on soil properties. Selection of sites that have comparable flooding conditions may also better elucidate effects of inundation under farmers' conditions.

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