LUCID's Land Use Change Analysis as an Approach
for Investigating Biodiversity Loss and Land Degradation Project

Land Use Change-Associated Deterioration in Soil Quality in Uganda: A Case Study from Sango Bay, Lake Mburo National Park Area and Kabale/Ntungamo Districts Border Area

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Land Use Change-Associated Deterioration in Soil Quality in Uganda: A Case Study from Sango Bay, Lake Mburo National Park Area and Kabale/Ntungamo Districts Border Area

The Land Use Change, Impacts and Dynamics Project
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I. INTRODUCTION

Land refers to all interacting biophysical attributes of the earth's surface including climate, general shape of the earth's surface, soils, hydrology, vegetation, fauna and relatively permanent improvements such as drainage channels and terraces (FAO, 1976). These attributes determine the potential utility of land (land use[1]): a major resource for man's economic livelihood. It is increasingly clear that long-term economic growth in most of sub-Saharan Africa depends upon sustaining and improving the productivity of its natural resource base, specifically, the land. This dependence is unfortunately associated with widespread land degradation, which is threatening sustainability of land productivity in much of the region, Uganda inclusive.

Focusing on the soil aspect of land, there is evidence that the soil resource in Uganda is degrading (declining in its capacity to produce quantitative and/or qualitative yields) (Tukahirwa, 1992; Opio-Odongo *et al*., 1993; Zake, 1993; Bekunda and Woomer, 1996; Bekunda *et al*., 1997). Subsequently, an index of per capita food production set at 100 in 1970 fell to 67 by 1990 in Uganda (World Bank, 1993). Therefore, there is an urgent need for policy makers to identify avenues that lead to the improvement and maintenance of productivity of the land in general and soils in particular, and set policies that lead to this important cause (Place and Otsuka, 2000). Any intervention could be most effectively and efficiently accomplished if it is rooted in a well-established information base pertaining to the state and dynamics of the land resources and their factor controls.

Cases around the globe indicate that land use change and its causative factors (such as policy regimes and demographic pressure) have been implicated in soil degradation, creating an entry point for policy level intervention. Examples are in Nigeria (Adejouwon and Ekanade, 1988); in Guam (Motavalli, 1998); in Paraguay and Brazil (Riezebos and Loerts, 1998); in Bangladesh (Islam and Weil, 2000). In Uganda, some work has been done to elucidate the impact of demographic pressure and/or policies on land use change and/or soil management (Opio-Odongo *et* al., 1993; Nsubuga, 1994; Place and Otsuka, 2000). However these studies need amplification to illustrate the influence of land use change on soil degradation that is hampering sustenance of productivity of the soil resource base in Uganda.

A. Theoretical Background

Historically, man has always settled on high agricultural potential lands first (Sanchez and Buol, 1975) and as populations rise, they spread out to less productive/marginal areas, often accompanied with alarming degradation of the land resources. Recently, environmental concerns have prompted wise use of ecologically sensitive and crucial areas (mainly natural forests, wetlands and wild life sanctuaries), particularly in settled agriculture. However, as per capita agricultural land diminishes, and defective policy regimes distort allocation mechanisms and/or access rights to land, rampant poverty has led to indiscriminate expansion of agricultural production to the ecologically sensitive zones, notably, the natural forests (Mahtab and Karim, 1992; Place and Otsuka, 2000).

Land use changes, especially cultivation of deforested land, may rapidly diminish soil quality leading to severe land degradation (Kang and Juo, 1986; Nardi *et al*., 1996; Islam *et al*., 1999). The conversion of forest to cropland has been associated with reduction in organic matter content of the topsoil (Ross, 1993; Singh and Singh, 1996) and subsequently, decline in productivity, since organic matter content is responsible for the productivity of tropical soils (Sanchez *et al*., 1997; Palm *et al*., 2001). Islam and Weil (2000) reported an increase in bulk density and a reduction in porosity and aggregate stability following the conversion of

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[1] The term land use denotes the human employment of land including settlements, arable cultivation, grazing pastures, range and forests. Land use involves the manner in which the physical attributes of the land are manipulated and the underlying intent.

forestland to cropland. Similar findings were reported by Motavalli (1998) and Riezebos and Loerts, (1998). Such changes in soil properties predispose the soil to soil erosion, a major causative agent for further soil degradation. However, the extent to which a given soil degrades depends on its relative sensitivity (ease with which the soil succumbs to degrading forces) and resilience (ease with which the soil rejuvenates naturally or responds to agrading management interventions) (Stocking and Murnaghan, 2001). The soil's sensitivity and resilience are thus related to a combination of the soil's inherent properties (which are in turn dependent on the soil formation factors, namely: parent material, climate, topography, organisms and time from onset of the soil formation process) and the soil's management history. This therefore implies that the quality status of a given soil may differ spatially and temporally owing to differential past management regimes.

Place and Otsuka, (2000) modeled tree cover change in central and eastern Uganda and reported an expansion of agricultural land at the expense of woodland, with population growth and land tenure system being significantly associated to the land use change. However, their study did not investigate the effect of the land use change on the associated soil properties. The Land Use Change Impacts and Dynamics (LUCID) project (Uganda Chapter) investigated land use (cover) change and the underlying demographic and policy factors in Sango Bay (Rakai district), areas around Lake Mburo National Park (Mbarara district) and Kabale/Ntungamo districts border areas in Uganda, which are reported in other documents. This report documents the associated changes in soil properties.

B. Specific Objectives

1. To assess the relationship between land use and selected soil quality parameters in Sango Bay, Lake Mburo National Park area and Ntungamo/Kabale districts border areas;
2. To quantify changes in selected soil quality parameters associated with land use change in Sango Bay, Lake Mburo National Park area and Ntungamo/Kabale districts border areas.

C. Hypotheses

1. There is a significant relationship between land use and soil quality parameters in Sango Bay, Lake Mburo National Park area and Ntungamo/Kabale districts border areas;
2. Conversion of land use from natural vegetation cover to arable land use leads to a deterioration in soil quality parameters in Sango Bay, Lake Mburo National Park area and Ntungamo/Kabale districts border areas.

Hypothesis 2 was tested on the assumption that originally there were no significant differences in the soil quality parameters measured between the land use types and that soil management levels were low among the land users. Any significant differences were then attributed to land use change. Results from the socioeconomic survey show that soil management levels in the study area are visibly low.

II. METHODOLOGY

Transects were laid out at each study site and soil samples taken randomly along each transect using a quadrant. The transects crossed the major soil units at each site (Mbarara, Bugangari and Ibanda series in Ntungamo site; Mbarara, Koki and Bukora series in Lake Mburo National Park area; Buganda catena and Sango-Bukora series in Sango Bay) (Figures 1-3), descriptions of which are given in Appendix 1. Composite soil samples were taken from the 0-15 cm (topsoil) and 15-30 cm (subsoil) depths in each quadrant and the corresponding land use was recorded. A total of 145 samples were collected and analysed for organic carbon

(OC), exchangeable bases (Ca, Mg and K) and extractable phosphorus (P) using standard laboratory methods.

Data were tested for normal distribution using the Boxplot procedure and the soil parameter statistics were then regressed on land use following the General Linear Model procedures in Genstat 6.0 computer software. A preliminary statistical analysis of the data revealed that the soil properties had a highly significant relationship with transects across the sites (perhaps due to the wide heterogeneity in soils, climate, landscape and soil management regimes) but no significant relationship with transects within a given site. This was contrary to the assumption upon which Hypothesis 2 was to be tested. Therefore to minimize errors/biases arising from the wide spatial heterogeneity (and hence differences in relative sensitivity and resilience) of the soils between the study sites, the hypothesis was tested by analysing the data for each site separately. A soil deterioration index (*RX*) was then computed for each site for each of the soil quality parameters using equation 1 adopted from Adejouwon and Ekanade (1988), to permit comparisons across the sites.

$$RX = \frac{(X - U) * 100}{U} \qquad \text{...} \quad \text{Equation 1.}$$

Where :

- RX is the relative change in the soil property;
- X the adjusted mean of the soil property from the land use under consideration (“disturbed land use”); and
- U the mean (regression analysis constant) of the same soil property from a reference land use at the site in question.

The reference land use at a given site was that reported by the land users and/or observed in the field to have had relatively stable or ‘undisturbed’ natural vegetation cover for a relatively long period up to the time of soil sampling and is known to be of relatively good arable potential.

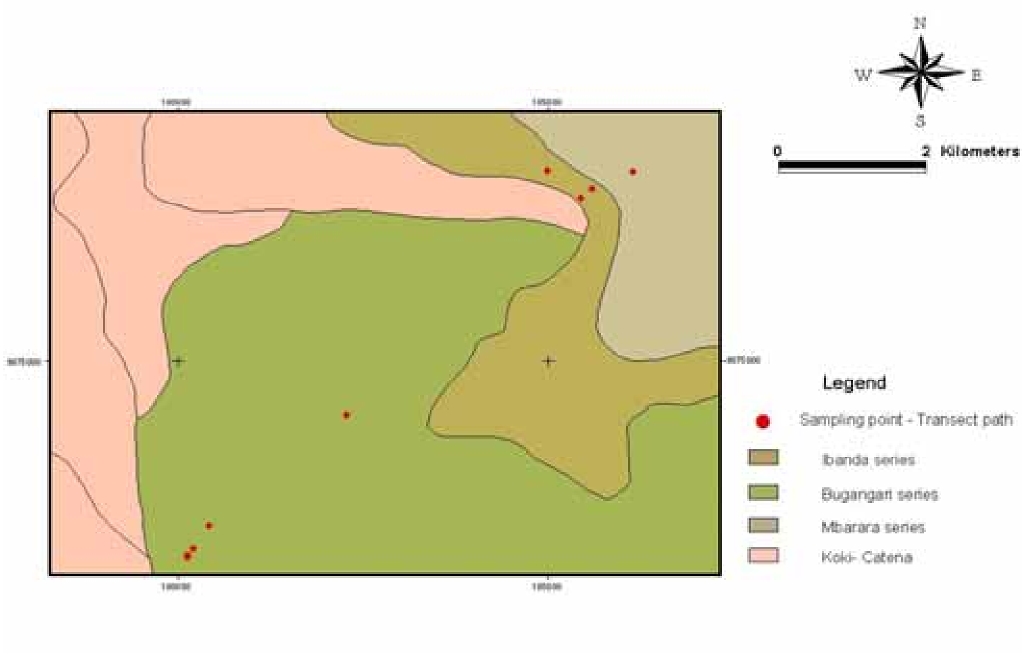

Figure 1. Soils and sampling points in Ntungamo site

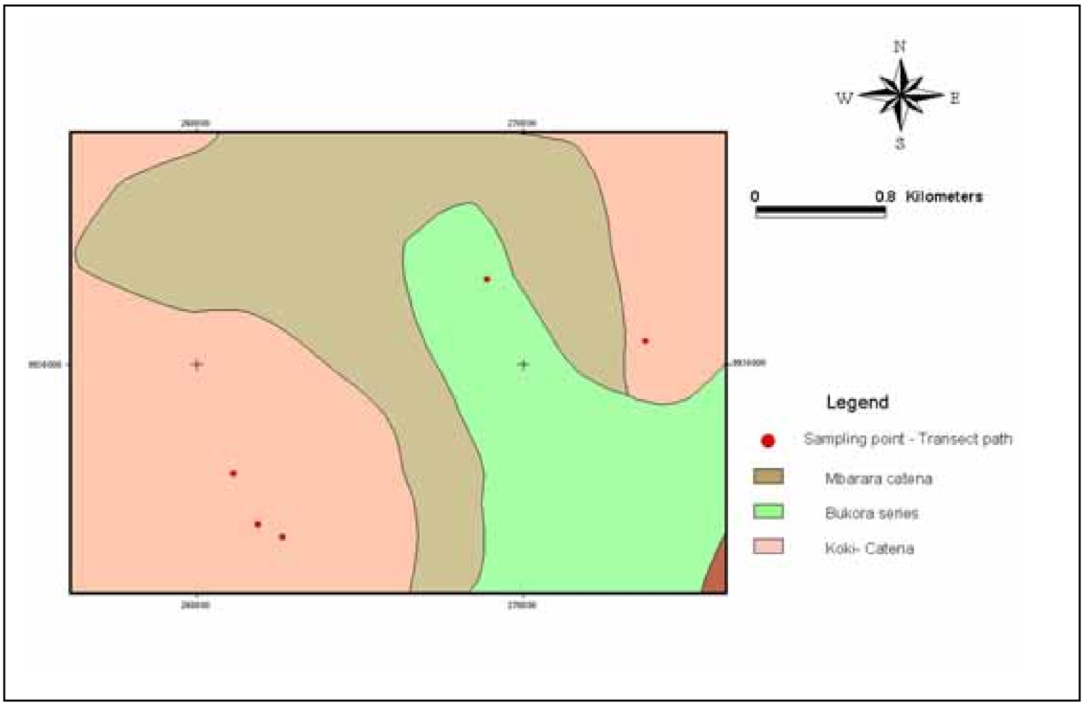

Figure 2. Soils and sampling points in Lake Mburo National Park area site

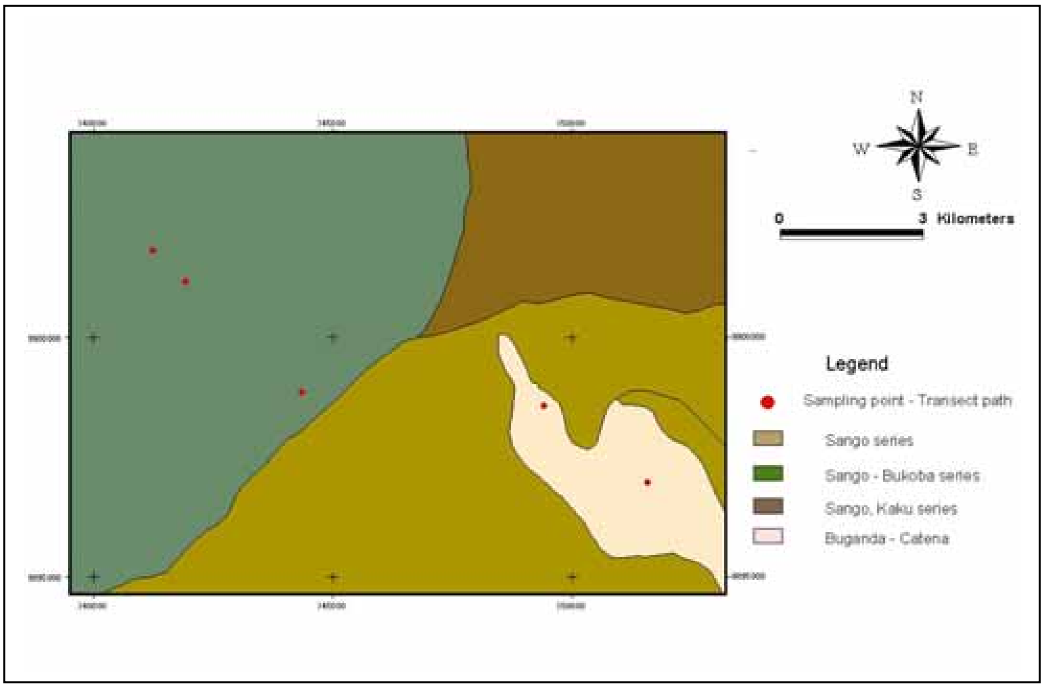

Figure 3. Soils and sampling points in Sango Bay site

IV. RESULTS AND DISCUSSION

A. Major Land use Types

The land use types at the study sites are presented in Table 1.

Table 1. Summary of land use types at the study sites

Land use	Ntungamo	Lake Mburo	Sango Bay	Description
Cultivation	4	4	4	Under annual/perennial crops
Fallow	4		4	Rested from crop production
Forest			4	≥ 80% woody tree cover
Woodland			η4	2-80% woody tree/shrub cover; rarely used for grazing livestock
Grassland	4		4	Grass cover; rarely used for grazing
Grazing grassland	η4	4	4	Grass cover; frequently used for grazing
Grazing woodland		4		2-80% woody tree/shrub cover; frequently used for grazing
Grazing woodland charcoal		4		2-80% woody tree/shrub cover; frequently used for grazing and charcoal burning
Undisturbed woodland		η4		2-80% woody tree/shrub cover; human activity prohibited

4= Major land use type; η = reference land use type

Note: Forest land use was not taken as the reference land use for Sango Bay site because it is located in marginally fertile Sango-Bukora soil series, which is not widely cultivated in the area. The woodland was used instead because it is located on the widely cultivated Buganda catena.

B. Relationship between Land use and Soil Quality Parameters across Sites

There was a highly significant ($P \leq 0.05$) relationship between land use and Ca, Mg and Ca contents of the top- and sub-soils across the sites (Table 2). The analysis was run with reference to cultivation land use.

Table 2. Summary of regression analysis of soil quality parameters on land use across sites

Parameter	Topsoil			Subsoil		
	F pr	e.s.e	R^2	F pr	e.s.e	R^2
Ca	<0.001	2.460	82.8	<0.001	2.480	80.4
K	ns	0.399	4.70	ns	0.314	9.8
Mg	<0.001	1.080	68.9	<0.001	0.800	79.1
OC	<0.001	0.854	78.3	<0.001	0.821	70.0
P	0.015	50.000	13.0	ns	6.500	60.8

ns = Not significant at 5% level; e.s.e. = estimated standard error.

The undisturbed woodland, to which all forms of agricultural production were forbidden, exhibited the highest adjusted means (relative to cultivation land use) across the sites for the soil properties that are significantly related to land use (Ca, Mg and OC) (Table 3).

Table 3. Adjusted means for land use type across sites

	Topsoil					Subsoil				
	Ca	K	Mg	OC	P	Ca	K	Mg	OC	P
Land use	(cmol/kg)			(%)	(mgP/kg)	(cmol/kg)			(%)	(mgP/kg)
Cultivated	5.31	0.58	2.22	1.56	60.6	4.63	0.479	1.79	1.39	62.5
Fallow	4.88	0.29	1.90	1.78	99.80	4.43	0.253	1.48	1.58	101.5
Forest	2.10	0.26	0.88	2.75	25.40	0.62	0.157	0.68	1.69	13.9
Grassland	1.66	0.16	0.57	2.21	34.70	-	-	-	-	-
Grazing grassland	3.66	0.37	1.59	2.46	12.70	12.60	1.190	5.80	4.44	76.5
Grazing woodland	6.17	0.76	2.98	2.26	5.0	5.85	0.235	3.02	2.16	3.8
Grazing woodland charcoal	8.65	0.25	3.25	3.25	5.9	7.25	0.390	3.10	2.49	4.5
Undisturbed woodland	19.44	0.52	6.21	6.56	49.9	16.43	0.343	5.37	4.55	34.2
Woodland	9.88	0.55	3.70	3.97	27.6	4.05	0.305	1.90	1.37	15.8
s.e.d	1.797	0.292	0.793	0.625	ns	0.476	0.060	0.154	0.158	ns
e.s.e	0.464	0.075	0.205	0.161	35.37	2.521	0.320	0.814	0.836	61.9
LSD$_{0.05}$	3.579	0.581	1.576	1.245	ns	5.064	0.642	1.636	1.679	ns

ns = Not significant at 5% level; s.e.d. = standard error of difference between means; e.s.e. = estimated standard error

Cultivation, which was not significantly different from fallow, exhibited low means of all the properties compared to the undisturbed woodland. Forest and grassland land use types had the smallest values except for OC. The low adjusted means for the forest land use are probably due to the low inherent fertility status of the forest soil (Sango Series) in Sango Bay, whereas those for the grassland may have been a result of nutrient losses through soil erosion resulting from regular bush burning.

The grasslands were situated on hill summits on soils with a laterite impeding layer at shallow soil depth (hence the absence of subsoil results), which hinders infiltration thereby increasing runoff. With the long-held tradition of burning grasslands towards the end of the dry season, the fragile soils are exposed to runoff at the onset of the rains, washing nutrient-laden sediments down slope. Deposition of such sediments partly explains the higher nutrient content of the woodlands further down the landscape.

Periodic tillage operations with insufficient soil and water management in the cultivation land on the other hand may be responsible for the significantly low OC content. Tillage loosens the soil, improving its aeration, which hastens microbial breakdown of soil organic matter through respiration. It also increases susceptibility of the soil particles to detachment and entrainment by water during the erosion process (Roose and Barthès, 2001). Nutrient losses also occur through crop removals in harvested products, a practice that is very common in subsistence economies.

Further loss results from leaching of nutrients in percolation water as a result of lowered cation exchange capacity (CEC) associated with reduction in organic matter content in tropical soils. The observed relationships between land use and nutrients may be due to differential rates at which these nutrient loss processes proceed in the land use types.

C. Land use change-associated deterioration in soil parameters across sites

There was a decline in topsoil Ca, Mg and OC corresponding to land use type at all sites (Figures 4, 5 and 6, respectively). The deterioration ranged from about 38% for topsoil Ca in cultivation land use in Sango Bay to over 110% for topsoil Ca in grassland land use in Sango Bay. The relationship of K with land use was not significant.

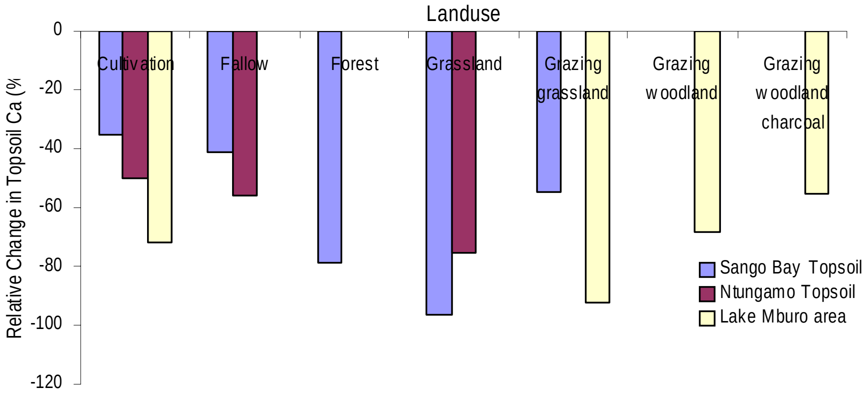

Figure 4. Relative change in topsoil Ca across the study sites

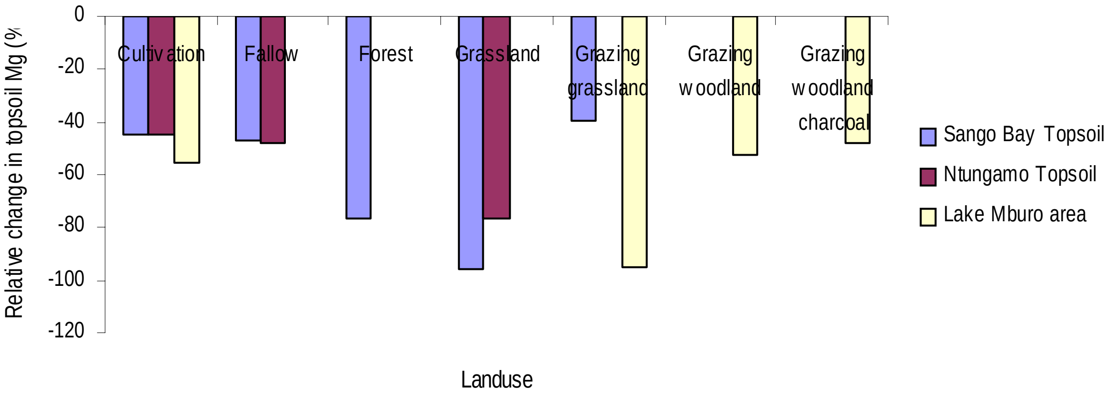

Figure 5. Relative change in topsoil Mg across the study sites

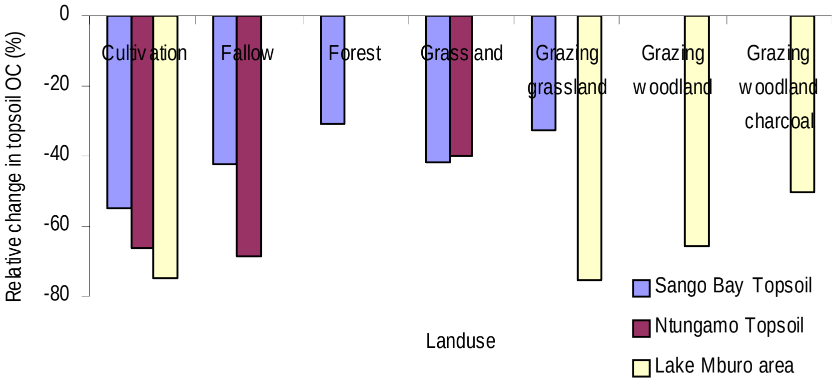

Figure 6. Relative change in topsoil OC across the study sites

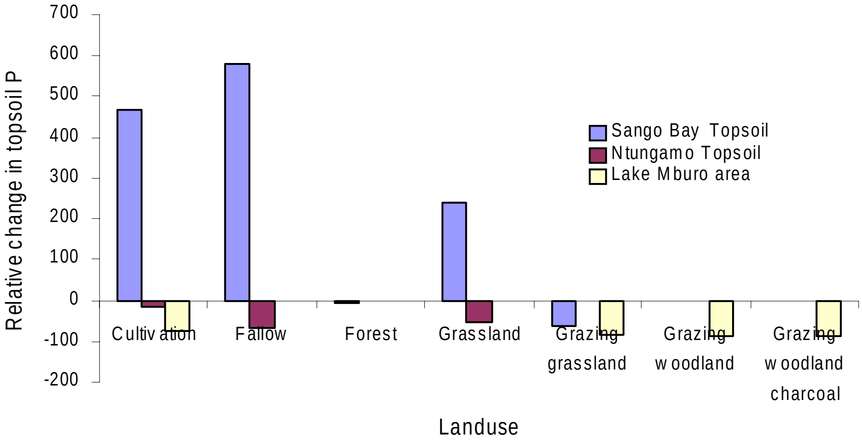

Figure 7. Relative change in topsoil P across the study sites

D. Effect of land use change on soil quality parameters

Computed soil deterioration indices showed that Ca, Mg and OC declined relative to their corresponding values in the respective reference land use types (Figures 4,5 and 6, respectively) at all the sites.

However, P increased in cultivation, fallow and grassland in Sango Bay (Figure 7). This may be due to depositions from external sources. P is known to be to accumulate in soil with repeated additions (Tisdale, 1993) due to its relative immobility in the soil. Soils around Sango Bay were reported to have accumulations of P from bird droppings (Radwanski, 1960). The general decline in the soil properties is an implicit manifestation of the impact of land use change on the soil resource.

Generally the results are in line with the findings of Kang and Juo (1986) to the effect that replacement of natural vegetation with agricultural production without adequate soil management leads to a decline in soil chemical and physical properties, culminating in falling crop yields. This implies that any factors that encourage/promote clearance of natural vegetation and/or discourage farmers from instituting sound soil and water management practices in their agricultural production will inevitably lead to degradation of soil resources. Among such factors are policies affecting access rights and the way land is utilized, and increase in population pressure on land.

There was little direct relationship between temporal variations in land cover in the study sites and to the degree of soil deterioration observed. For example, Mugisha (2002) reported a 50%

increase in cultivation in Lake Mburo National Park area at the expense of natural vegetation cover compared to only 4.3% in Sango Bay area, but the soil deterioration indices for the two sites for the same land use types were generally similar. This suggests that soil degradation is increasing in aerial extent rather than in intensity in Lake Mburo National Park area, i.e., the increase in population is leading to degradation of the soils through cultivating hitherto unused parcels of land rather than through mining those already in use, as in Sango Bay.

This is a potentially dangerous situation given the rising population and associated demands for food, fodder, fuel and fiber in the country, and that the demands are to be met with a finite soil resource. An expansion of degraded land would result in a shrinkage of productive land area when demands from it are rising. This situation calls for objective land use planning to guide the allocation of land use to different parcels of land. This would be done in accordance with a land capability and suitability classification, and take into account the requirements of a given land use from the soil, the inherent capacity of the soil to meet these requirements and the degradation hazard associated with the decision to allocate the land to the land use.

Spatially explicit soil resource data in terms of inherent soil properties (obtainable through GIS-linked modeling of soil quality) and susceptibility to erosion (obtainable through GIS-linked modeling of soil loss hazard) would greatly aid this process. This would permit the necessary increases in the production of food, fodder, fuel and other outputs from the land in without compromising the long-term productivity of the soil resources.

IV. CONCLUSIONS

There is a significant relationship between land use and soil properties. The change in land use from natural vegetation cover to cultivation and grazing without sound soil management is leading to deterioration of the soil.

Recommendations

Although the conclusion from the study was arrived at objectively, it was based on analysis of a limited data set. It should therefore be concretized with spatially explicit data that can handle spatial heterogeneity in the climate, landscape, soil properties, and soil management regimes of the study area. GIS-linked modeling of soil quality and soil degradation processes is one way in which this can be achieved. For example, Lufafa *et al*. (2003) modeled soil degradation through erosion using a GIS-linked Universal Soil Loss Equation capable of overcoming the confounding effects of spatial heterogeneity and also permit interpolation from spatially well distributed point observations. A similar approach could be used to concretize the findings of this study.

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Appendix 1. Soils of the study sites

Site	Soil Type	Parent material	Texture and other characteristics
Ntungamo	Mbarara series	Phyllites and Quartz, Schists	Yellowish red loams and sandy loam with occasional soft laterite
	Ibanda series	Toro Schists and Amphibolites	Red sandy clay loams
	Bugangari series	Granites, Gneisses, Schists, Amphibolites	Shallow dark brown or sandy loams often very stony
Lake Mburo National Park area	Koki catena (same as for Ntungamo site)	Karagwe-Ankolean, Phyllites	Reddish brown clay loam
	Mbarara catena	Phyllites and Quartz, Schists	Yellowish red loams and sandy loams with occasional soft laterite
	Bukora series	Recent river alluvium	Dark brown sandy loam
Sango Bay	Sango-Bukora series	-	-
	Buganda catena	Toro Schists and Phyllites	Red sandy clay loams often underlain by soft laterite
	Sango series	Lake deposits	Grey coarse sands
	Sango-Kaku series	-	-