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COMPARATIVE DESCRIPTION OF LAND USE AND CHARACTERISTICS OF BELOWGROUND BIODIVERSITY BENCHMARK SITES IN KENYA

[DESCRIPCION COMPARATIVA DE USOS DEL SUELO Y CARACTERISTICAS DE LA DIVERSIDAD DEL SUBSUELO EN SITIOS EMPLEADOS COMO REFERENCIA EN KENIA]

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SUMMARY

The Kenyan below-ground biodiversity (BGBD) team selected two benchmark sites for the inventory of soil biota which were the Irangi and Ngangao forest sites located in Mount Kenya region of Embu District and the Taita Hills area of Taita Taveta District. These two sites are found in biodiversity hotspots that support rare and endemic plant and animal species. The larger Embu and Taita benchmark areas were demarcated into sampling areas which are referred to as windows 'W' in this study. Site characterization was carried out using the method provided by FAO-UNESCO for characterizing and classifying soils. Further to this, attempts were made to establish land use intensity (LUI) and land productivity (PI) indices that provided land condition indicators. The soils in Taita Taveta benchmark site were classified as Plinthic Lixisols, Plinthic Acrisols, Dystric Cambisols and Chromic Luvisols, while those from Embu ones were Rhodic Nitisols, Humic Nitisols, Humic Acrisols, Haplic Acrisols and Umbric Andosols. The highest level of soil organic carbon recorded was 7.6% in forest soils while the intensely cultivated maize-based and horticultural systems recorded low C levels of 1.6%. Low land use intensity gradients (LUI) were observed in the forests with values less than 2%, while horticulture and maize-based systems recorded more than 30%LUI. The productivity index (PI) followed a similar trend being highest in the natural forest and grassland (40-50%) and lowest in horticultural and maize-based systems (15-20%) It was concluded that the decline in soil quality and productivity was linked to increased land use intensification due to lack of knowledge of the appropriate management practices for sustainable ecosystem functions and services.

Key words: Soil characteristics; soil quality; productivity index; land use intensity index.

INTRODUCTION

Soil fertility degradation and decline in productivity have been described as important constraints to food production and security in Sub-Saharan Africa (Bationo, 2005). Scientific research has contributed immensely to the improvement of agricultural practices. However, despite the availability of high yielding and pest resistant varieties of major crops, there is still a large yield gap between the potential yield provided by scientific experiments and the yield obtained by farmers in Africa, leaving sub-Sahara Africa experiencing food insufficiency and insecurity (Boutfirass *et al.,* 1999). For example, in BGBD project research sites, the potential yield of maize is 4,000 kg per hactare, while the yield obtained by the farmers is on the average only 900 kg per hectare. The existing secondary data on food security including the findings from Fertilizer Recommendations Project (KARI, 1987) indicated that loss of soil quality and productivity was caused by increased soil acidity, aluminum toxicity, and poor soil structure and reduced soil depth. The decline in soil quality and productivity, caused by the increasing land use intensification was the most possible explanation for loss of below-ground biodiversity (BGBD) and agricultural sustainability in the research sites (Muya et al., 2008). Restoration of the degraded land for enhanced ecosystem services and agricultural production requires baseline data on chemical and physical characteristics of soils in relation to its productivity across land use gradients.

Understanding soil organisms requires good knowledge of their habitats and their associated relationships. In a balanced soil, plants grow in an active and vibrant environment. The mineral content of the soil and its physical structure are important for their well-being, but it is the life in the earth that powers its cycles and provides its fertility. Characterization of the below-ground biodiversity was undertaken to provide baseline data on the land resource to act as the basis for contextualizing the type of soil organisms, their diversity and the type of environment that the different organisms thrived. The inventory included the description of the bio-physical and chemical as well as the socio-economic environment of the two areas in Kenya; the Embu and Taita Benchmarks areas of the project.

MATERIAL AND METHODS

Description of the Embu and Taita Taveta benchmark sites

The Embu site is located around Irangi forest and its environs in the northern part of Embu town which is in the Mount Kenya region in the central part of the country. It is located at longitudes 37° 18' East and Latitudes 0° S and 0° 28'S. The site was selected because it offered a land use intensification gradient, starting from natural forests to intense utilization in the cultivated croplands. The altitude of the cultivated regions varied between 1,200 and 2,000 metres above the mean sea level while the snowline is at 5,000 metres above the sea level. The alfo-alpine belt occurs between 3,800 and 4,500 metres above the sea level. It contains a more varied flora than the snow caped mountain tops. These include *Lobellia telekii* and *Lobella keniansis*, *Senecio keniodendron* and *Craduus spp*. The lower alpine moorland occurs between 2,800 and 3,500 metres above the sea level. It is characterized by high rainfall, thick humus layer and species richness. The Tussock grasses, *Festuca pilgeri* and *Sedges carex* spp. are the major natural vegetation in the region. In the lower region, bamboo forest, followed by indigenous forests, natural grasslands, including a mixture of natural and planted forests are found.

The second site which is situated in the Taita-Taveta District in South-Eastern Kenya, Coast Province and it lies along longitude 38°20´ and latitude 3°25 (Figure 1). It covers an area of 1000 km^2 and they form the northernmost part of the Eastern Arc Mountains. This benchmark area falls within the tropical moist highlands climate like the Embu one. The ecological regions include: the mountain forest, with the highest point, at 1952 meters above the sea level. The indigenous and planted forests of Taita hills were found to occupy the upper highland regions, mainly mountains, while agroforestry and shrubs were found on the footslopes, hills and uplands, and annuals and perennials dominated the bench-terraced uplands.

Soil Sampling and analysis

Methods and criterion for site selection and sampling were based on the protocol agreed upon by the seven countries participating in below-ground biodiversity (BGBD) research (Moreira et *al.*, 2008). In each benchmark, site, sampling areas were marked and labeled "windows" each window covered an area of about 6 km^2. The Embu benchmark windows were designated E1, E2 and E3 with E1 located in the lower annual crops landscape, window E2 in the coffee-tea zone and window E3 in the upper tea-forest landscape. In Taita, the windows were designated as T1 and T2. T1 was on the lower landscapes with intensive cropping systems while window T2 was in the upper uplands covered partly by forests. Within each benchmark area, 100 sampling points were selected for sampling at each of the benchmark sites. At each sampling point, soils were taken using a soil auger to a depth of about 120 cm to use for soil type characterization including depth, colour, texture, consistence, surface sealing, crusting and compaction. Based on these characteristics, the representative soil profiles were identified, described, sampled and classified according to FAO-UNESCO Soil Map of the World (1997). From the same sampling points, one kiligramme composite soil samples were collected for laboratory determinations using standard procedures applied at the National Agricultural Research Laboratories as described by Hinga *et al*., (1980). The soil properties analyzed were available plant nutrients (P, K, Na, Ca and Mg) using the Mehlich double Acid Method (Anderson and Ingram, 1993), total organic carbon: using Calorimetric method (Nelson and Sommers, 1982),total nitrogen: using micro-Kjeldahl method (Page *et al.*, 1982), pH in 1:1 (w/v) soil – water suspension. And the micronutrients using the EDTA method (Okalebo *et al*., 2002).

Figure 1: The location of the benchmark sites in Kenya

Determination of land use intensity index (LUI)

Land use intensity index was calculated, based on the quantity of inputs applied per ha, frequency of the inputs application, cropping intensity (number of crops per season) and cultivation intensity. The maximum combined intensity of these components was assigned the value 1, so that each component out of the four contributed a value of 0.25 to the final score value of 1, as is defined in Table 1.

The land use intensity index was calculated for maize/beans, coffee, napier grass, tea, natural and planted forest, horticulture and fallow for all the windows.

Equation 1. At any location, the land use intensity index (LUI) was calculated, using the following equations.

$$LUI = \sum \left(\frac{Y + f + Cr + Cu}{Ni..} \right)$$

Where:
LUI= Land use index.
Y = Total quantity of organic and inorganic inputs applied,
f = Number of times the inputs are applied per growing season,
Cr = Number of crops per growing season,
Cu = Frequency of cultivation per year,
Ni = Number of input variables used (in this case 4)

Equation 2. The input intensity index was calculated by the following equation:

$$Yi = \left(\frac{Xi}{Max} \right) * 0.25$$

Where:
Yi = Input intensity index at any location,
Xi = Quantity of inputs applied at a specific site in a locality in kg/ha.
Max = Maximum amount of inputs applied in a locality in kg/ha

Equation 3. The frequency of input application index was calculated as follows:

$$Fi = Vfi * 0.25$$

Where:
fi = Frequency of input application index,
Vfi=Frequency of input application per season

Equation 4**:** The cropping intensity index was calculated as follows:

$$YCr = (XCr / 10) * 0.25$$

Where:
YCr=Cropping density intensity at a given point,
XCr = the number of crops per season

Equation 5: The cultivation intensity index was calculated as follows:

$$YCu = (XCu / 3) * 0.25$$

Where:
YCu = Cultivation intensity index,
XCu = the frequency of cultivation observed at a given point

Statistical Analysis

Soil property attributes and productivity indices were analyzed statistically using SPSS Statistical Computer Software Version 15.0, in which analysis of variance was carried out**.** The land use types were characterized by their chemical properties whose means were compared using ANOVA in Genstat Version 9.0. There was a further multivariate exploration where the soil chemical properties were constrained by the land use types and the results displayed in ordination plots.

Table1. Components of landuse intensity and the assigned values.

Components of LUI	Indicators/criteria	Assigned values	Remarks
Use of agricultural inputs	Total quantity of organic and inorganic inputs applied in the research site.	0.25	This value was assigned to the highest level of inputs observed in the research site.
Frequency of inputs application	Number of times the inputs are applied per growing season.	0.25	This value was assigned to the highest frequency of input application, which is 3 times per growing season.
Cropping intensity	Number of crops per growing season.	0.25	This value was assigned to the highest number of crops per growing season, which is 10.
Cultivation intensity	Frequency of cultivation per year.	0.25	This value was assigned to the highest frequency of cultivation, which is 3 times per year.
Combined influence of the four components		1.00	Land use intensity index number.

RESULTS AND DISCUSSION

Effects of land use intensification on chemical characteristics

Soil properties are the major soil quality indicators that can be linked to land use intensification in order understand the effects of land use on soil productivity. Results showed that land use intensity index was highest in maize-based and horticultural systems in both sites with values ranging from 30 to 40%. It was found to be lowest in the forests and grasslands with values less than 2%. Soil productivity index took a reverse trend, being highest in the forests (50-70%) and lowest under intensively cultivated area (10-30%). Land use types and management practices had significant influence on soil quality. In Embu, acidity, which was an important measure of soil fertility status, especially with regards to nutrient release, was found to be highest under tea and lowest in napier grass. This corresponded to availability of chemical bases, with Ca level being highest in napier, indicating accumulation of nutrient bases under napier as compared to other land use types (Table 1). The total nitrogen in the soil was generally high under most of the land use types in Embu. However, due to high acidity mineralization of a nitrogen, release and availability to plants was hampered which implied that the actual amount of available nitrogen in soils was low. Similarly total phosphorous and acidity levels were highest in soils collected from the tea plots which partly could be explained by the high fertilizer use on the crop but, availability of P to plants may have been limited due to fixation by Al^{+3} and Fe^{+3} that contributes to the high value of soil acidity rendering the nutrient unavailable to plants. The level of carbon was significantly different under different land use types, being highest in planted forest, with values over 6.4%. In Taita Taveta, acidity was highest under planted forest, while nitrogen was highest in indigenous forest. Phosphorous was also highest in indigenous forest, while organic carbon was highest in the planted forest. Acidity was lowest under napier, while low nitrogen, carbon, phosphorous contents were observed in soils from the maize plots (Table 2). Generally, soils from the Taita Taveta benchmark site had higher phosphorous and potassium as compared to soils form Embu site. Multivariate analysis (Figure 2) shows that coffee, maize, tea, napier and natural forest correlated significantly with the soil chemical properties. In Embu, it was found that the soil chemical properties could be explained by factor one which accounted for 71% of the variations. The factor mostly likely direct and indirect soil management practices under different landuse type , For instance high Cu in soils in Embu could be explained by the intensive pesticide use on coffee which agrees with data in Table 2 Similarly, N and C were highly correlated with the undisturbed natural systems such as the forests and pasture fallows. In Taita Taveta, an interesting but significant relationship was observed between the soil properties and landuse types where soil properties are pulled towards LUT with least soil disturbances such like napier, indigenous forest and planted forest Figure 2 .It was evident that acidity ,Fe and the organic components which include N and C correlated very strongly with the forest landuse type.

Table 2. Chemical characteristics of soils form Embu.

Land use type	pH	Acidity %	C %	N %	P mg/kg	Ca Cmol/kg	K Cmol/kg	Na Cmol/kg	Zn ppm	Fe ppm	Mn ppm	Cu ppm
Coffee	3.8	2.1	3.8	0.3	13.0	1.8	0.4	0.2	8.4	39.1	0.5	21.9
Fallow/ Pasture	4.3	1.2	5.6	0.7	14.3	2.4	0.5	0.3	16.6	32.4	0.6	0.9
Maize	4.2	1.1	3.3	0.4	16.0	2.4	0.5	0.4	10.4	40.9	0.7	3.9
Napier	4.2	0.8	3.5	0.3	11.4	2.5	0.3	0.3	9.2	33.3	0.7	4.9
Natural Forest	3.4	2.3	5.6	0.6	21.0	3.3	0.4	0.3	5.9	89.4	0.5	0.9
Planted Forests	3.9	2.1	6.4	0.8	13.1	1.9	0.2	0.2	5.1	58.9	0.2	3.6
Tea	3.5	2.9	4.5	0.0	20.9	1.9	0.2	0.1	3.4	52.1	0.4	0.6
P =<	0.001	0.001	0.001	0.001	0.002	0.031	0.001	0.001	0.001	0.001	0.001	0.001

Comparison of the means using ANOVA was also carried out and the land use types were found to be significantly different based on the soil properties

Table 3. Chemical characteristics of soils form Taita Taveta.

Land use type	pH	Acidity %	C %	N %	Ca Cmol /kg	Mg Cmol /kg	Na Cmol /kg	K Cmol /kg	P Mk /kg	Mn ppm	Zn ppm	Fe Ppm	Cu ppm
Coffee	4.8	0.4	1.8	0.2	2.10	2.3	0.2	0.30	14.4	0.3	3.8	41.1	0.7
Fallow	4.4	0.8	1.7	0.3	3.50	2.4	0.3	0.40	42.1	0.4	1.9	48.2	0.8
Horticulture	4.9	0.3	1.8	0.2	2.34	2.4	0.3	0.56	53.4	0.8	4.1	49.8	0.9
Ind. Forest	4.0	1.1	2.7	0.5	2.60	1.2	0.3	0.30	27.0	0.7	3.6	76.7	1.33
Maize	4.6	0.3	1.7	0.2	2.57	2.2	0.2	0.38	12.5	0.7	4.5	31.1	1.90
Napier	4.9	0.3	1.9	0.3	3.40	3.7	0.3	0.76	58.3	0.5	6.2	44.1	1.76
Planted Forest	3.5	2.0	2.3	0.4	2.36	1.2	0.3	0.17	5.8.0	0.8	4.6	89.4	1.08
P =<	0.001	0.001	0.001	0.001	0.018	0.001	0.28	0.002	0.019	0.006	0.002	0.001	0.001

Comparison of the means using ANOVA was also carried out and the land use types were found to be significantly different based on the soil properties

Landforms, Soils and Land degradation at the two benchmark sites

The landforms present in the different landuse types and their distribution in the Embu area are presented in Table 4 and Figure 3a&b. The forests occur in the upper level uplands whereas tea and coffee plantations occur in the volcanic footridges. The tea plantations that occur next to the forest belts are mostly mono-cultures of the crop with scattered trees acting as windbreaks in the monocropped tea plantation landscape. At the lower altitude is the mixed coffee annual crop plantations that fall in mid-latitudes where the temperatures are warmer than those in the lower moorland, forest and tea belts. The ecological region below the coffee belt is mainly covered by maize and in places with maize-bean intercrops. The bottomlands are mostly poorly drained with horticulture and arrow-roots as the predominant crops (Figure 3a).

The soil map legend is a combination of physiographic and soil characteristics with the physiography denoted by the symbols RI for volcanic footridges, L for plateau, U for uplands and B for bottomlands (Figure 3b).

The soils in the region vary form volcanic Humic Andosols in the upper level uplands to Rhodic and Humic Nitisols in the volcanic footridges and the plateau (Figure 4). The soils are generally dark reddish brown to dusky red, well drained, deep to extremely deep, with moderately strong to very strong structure, friable clay loam to clay and are sticky and plastic when wet. The soils generally have good workability, and are highly permeable and porous with high available soil moisture holding capacity. In places, particularly under coffee, the soils tend to be massive, breaking into weak, fine angular blocky structure. In intensively cultivated areas, the soils are pulverized, and have relatively low aggregate stability, hence vulnerable to water erosion. In other areas, particularly under tea, the soil structure comprises strong crumbs, permeated with very high rooting density, high porosity and low bulk density Table 4.

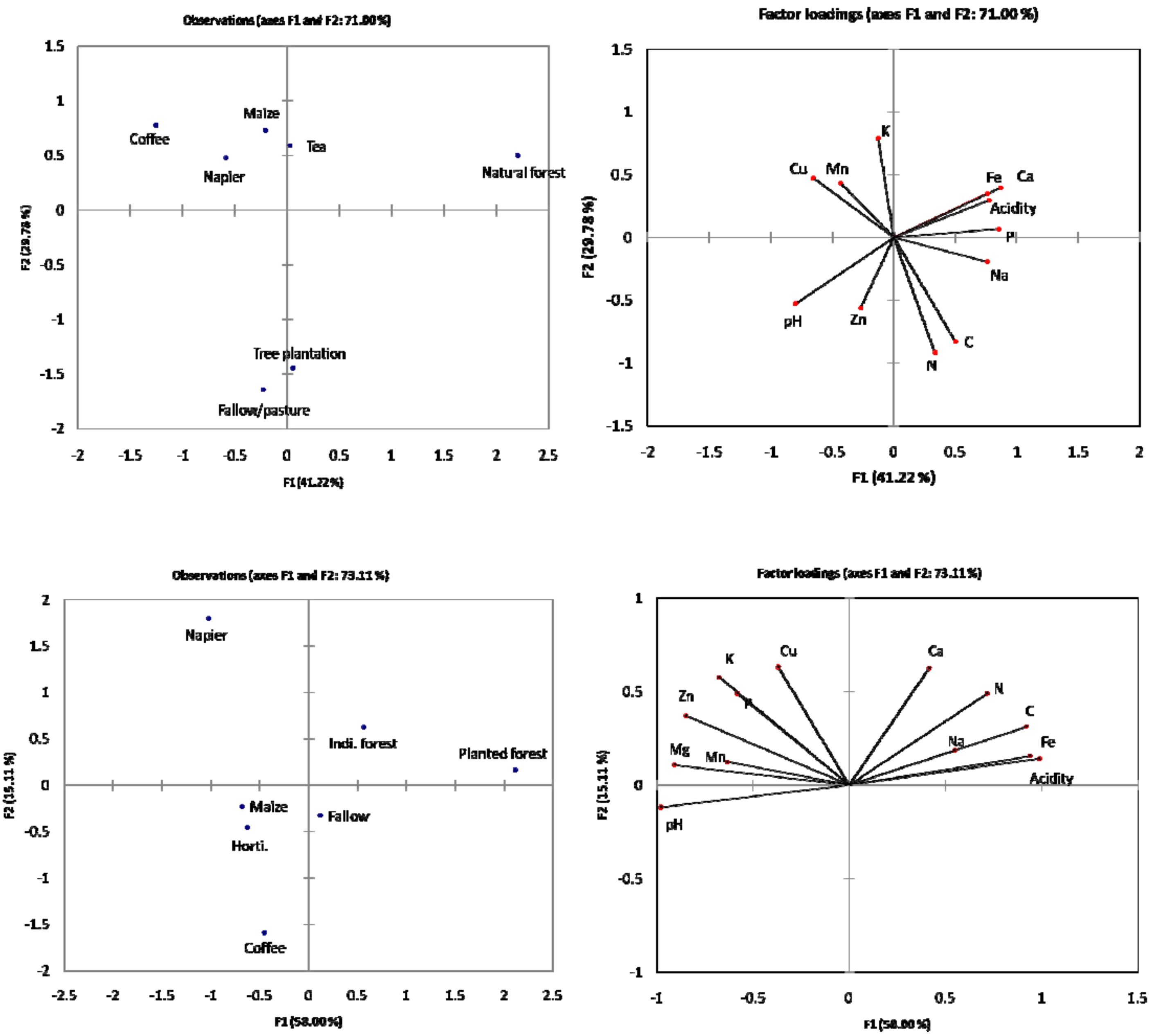

Figure 2. Multivariate analysis of land use classes and soil chemical properties showing relationships between the land use classes and the soil chemical properties (top-Embu and bottom-Taita).

Table 4. Description of the ecological regions and the degree of land degradation of Embu site.

Topographical characteristics		Soils	Land use and management systems	Degree of land degradation
Physiographical position	Dominant slope (%)			
Upper level uplands	15-80	Extremely deep, very friable, clay loam to clay with bulk density less than 1.0 g/cc	Natural forest, natural grassland, planted forest, tea and dairy farming.	Low
Volcanic footridges	10-65	Deep to very deep, friable clay loam with crumby soil structure.	Tea and coffee	Moderate
Plateau	0-5	Extremely deep clay with weak soil structure, breaking into dust.	Maize-based systems.	Low
Bottomlands	0-1	Poorly to moderately drained stratified sandy loam to clay.	Mixed cropping and horticulture.	Very low

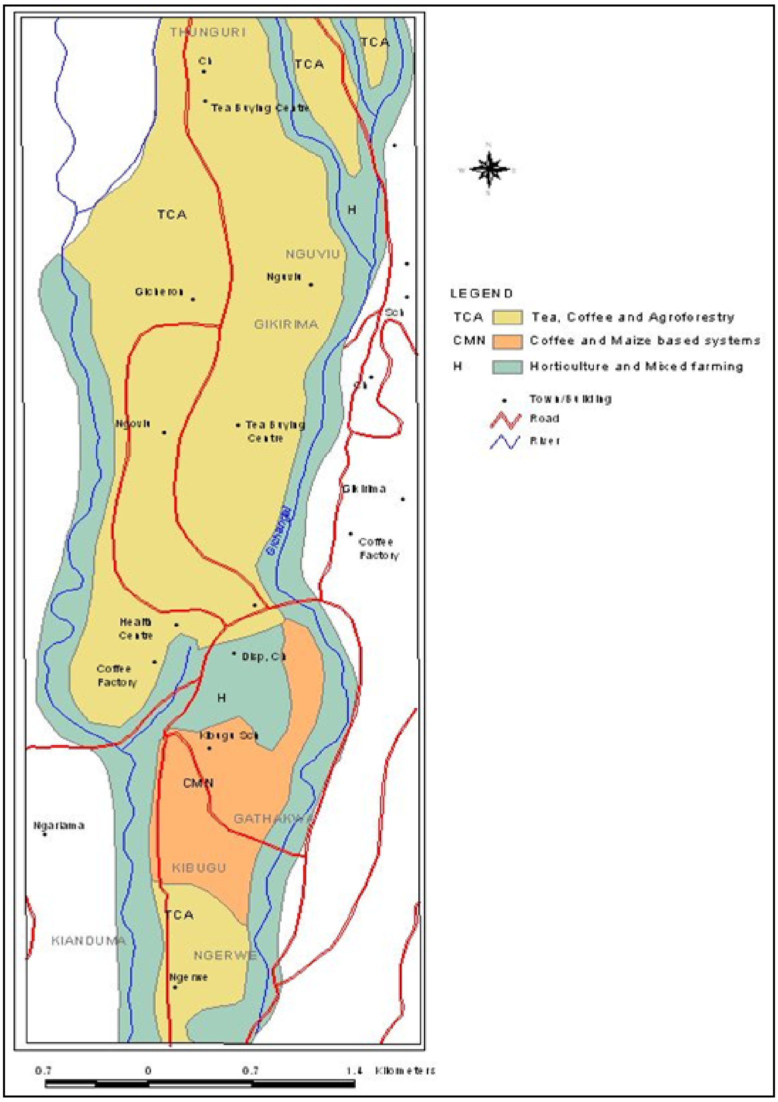

Figure 3a: Land use kinds in the Embu Benchmark Area

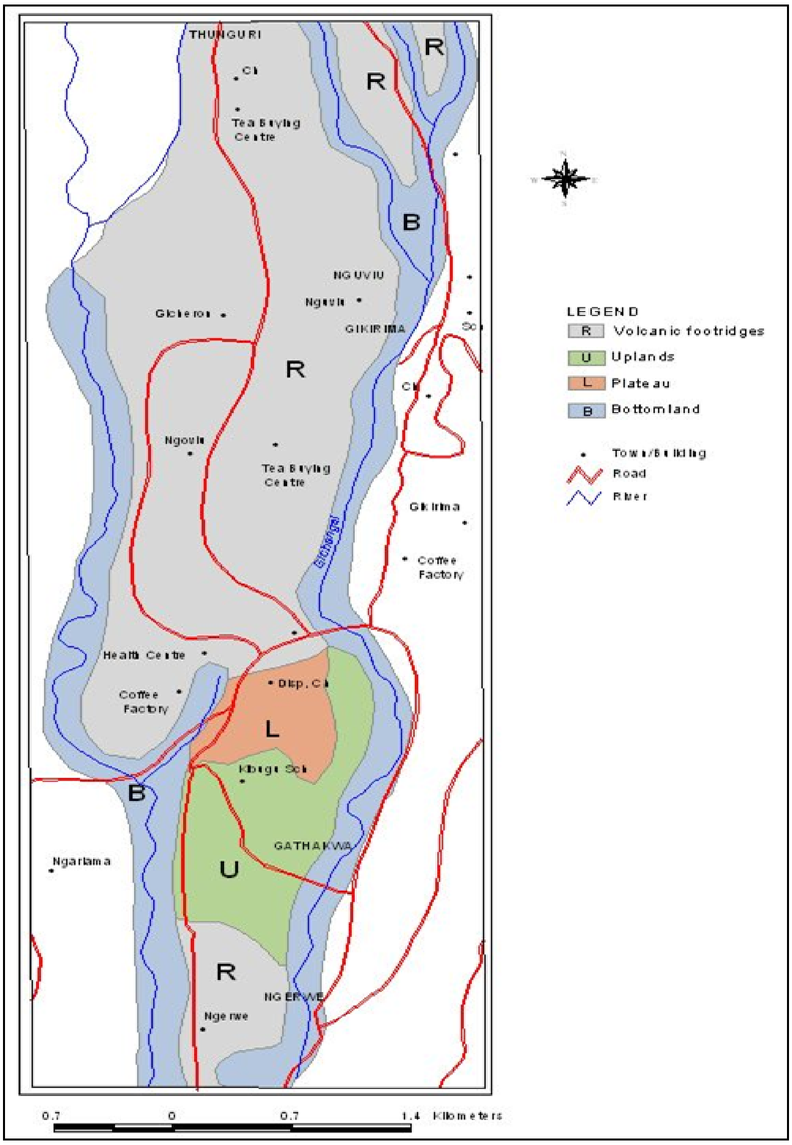

Figure 3b: Landorms in the Embu Benchmark Area

Landforms occurring in the Taita Taveta area including type of vegetation cover and the degree of degradation are presented in Table 5 and Figure 5a and 5b shows the landuse and soil types and their distribution. The mountain crests have moderately deep sandy clay loam soils having natural and planted forests as the main land cover types. The mountain mid-slopes have shallow, friable, boulders and gravelly clay loam with places having rock outcrops. The mid-slopes are generally poor in vegetative cover with a very high degree of degradation. The higher level uplands have deep to extremely deep friable sandy clay loam soils supporting agroforestry and shrubs as the main land cover types occurring in the area. Below these uplands are benched terraced lower lever uplands with deep to very deep clay soils supporting annual and perennial croplands. Below these lower level uplands are bottomlands that have extremely deep, loose to friable stratified sandy clay loam to clay soils that support mixed cropping including horticulture. The land degradation here is low.

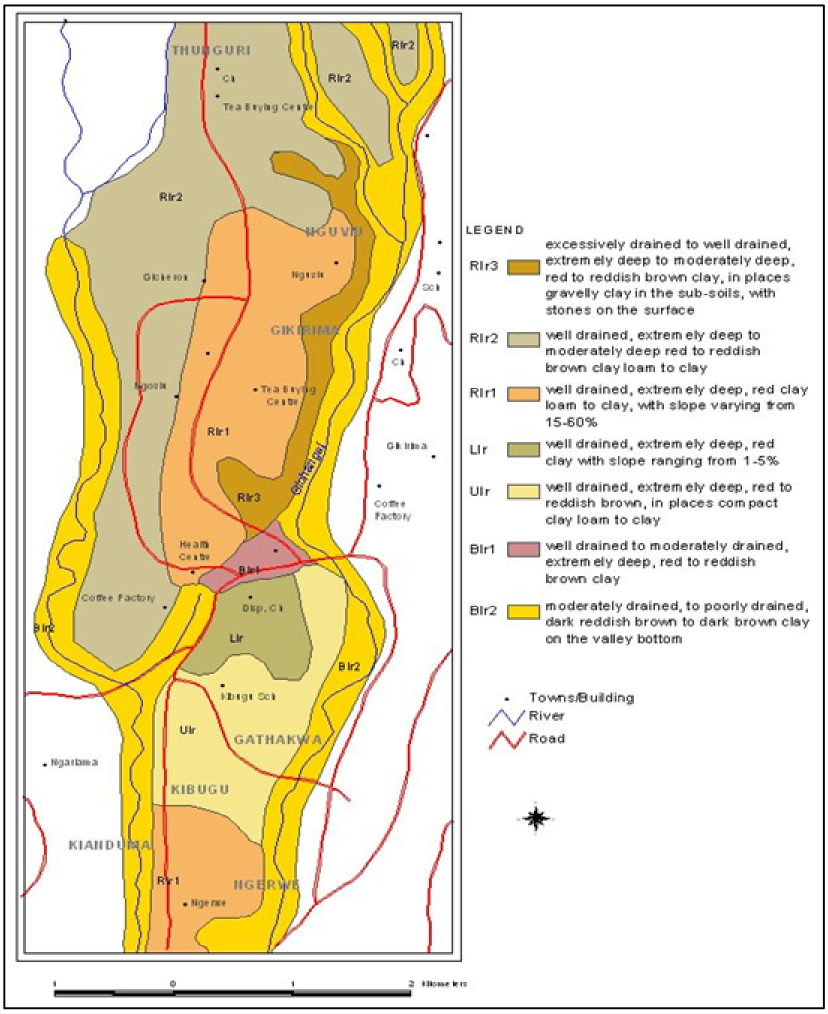

Figure 4. Soil types in the Embu Benchmark Area

Table 5: Description of the ecological regions and the degree of land degradation of Taita Taveta

Characteristics of ecological regions			Land use and management systems	Degree of land Degradation
Topographical characteristics		Soils		
Physiographical position	Dominant slope (%)			
Mountain crests and slopes	20-50	Moderately deep, friable, sandy clay loam.	Natural and planted forest.	Moderate
Mountain mid-slopes with rock outcrops	50-70	Shallow, friable, bouldery, rocky, stony, gravelly, clay loam to clay.	Poor vegetation cover	Very high
Higher level uplands, hills and footslopes	20-60	Deep to extremely deep, friable, sandy, clay loam.	Agroforestry and shrubs.	High
Bench-terraced lower level uplands	5-16	Deep to very deep clay.	Annual and perennial cropping.	Low
Bottomlands	0-1	Extremely deep, loose to friable, stratified sandy clay loam to clay.	Mixed cropping and horticulture.	Very low

Similarly, in Taita Taveta, the first entry into the soil map legend is physiography denoted by the symbol M for mountains, U for uplands and B for bottomlands. The soils are generally well drained to excessively drained, shallow to extremely deep, friable to extremely compact, dark reddish brown to red, loamy sand to clay. The firm and compact soils have poor soil structure, reflected in relatively low water uptake and retention capacity, hence high volume of run-off, leading to excessive erosion. For benchmark sites, the sequence and distribution patterns of the major soils are related to geomorphic characteristics of the area (Figures 5a and 5b).

Comparative description of the biophysical characteristics and the soils of two benchmarks sites

The main land use systems across the two benchmark sites are natural and planted forests, fallow/grassland, and cropland with tea, coffee, maize/beans and horticulture. They are found on landscapes with varying land, biophysical and climatic characteristics (Table 6). At the Embu benchmark site, the geology comprises mainly of tertiary basic igneous rocks covering all the trhee windows (E1, E2 and E3). The geomorphologic features are uplands, volcanic footridges, plateau and bottomlands Table 6.. Most uplands sites in Taita Taveta are underlain by the undifferentiated precambrian rocks, while mountains, footslopes and hills are underlain by quartz-feldspar gneiss and felsic granulites. The geomorphic features common to all the benchmark areas are upper level uplands and differences in climatic characteristics between the two benchmark sites occur within a narrow range. However, soil characteristics are very variable,for instance in Embu, the soils are friable, and in places with smeary consistence and humic topsoils, while in Taita Taveta, they are mostly very firm and compact. The main soil types in Embu are Nitisols and Andosols and in Taita Taveta Acrisols, Cambisols, Luvisols and Regosols are common.

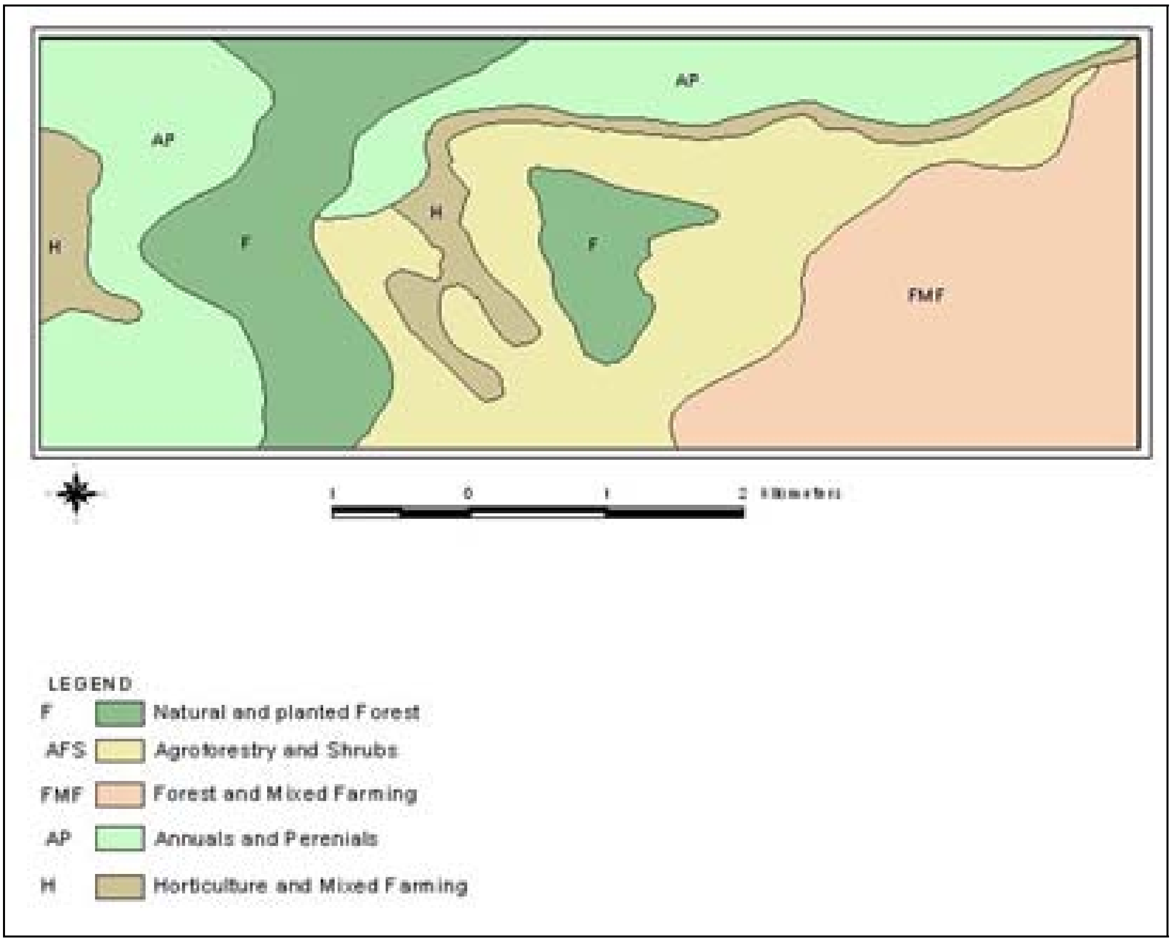

Figure 5a: Land cover and land use types in the Taita Taveta Benchmark Area

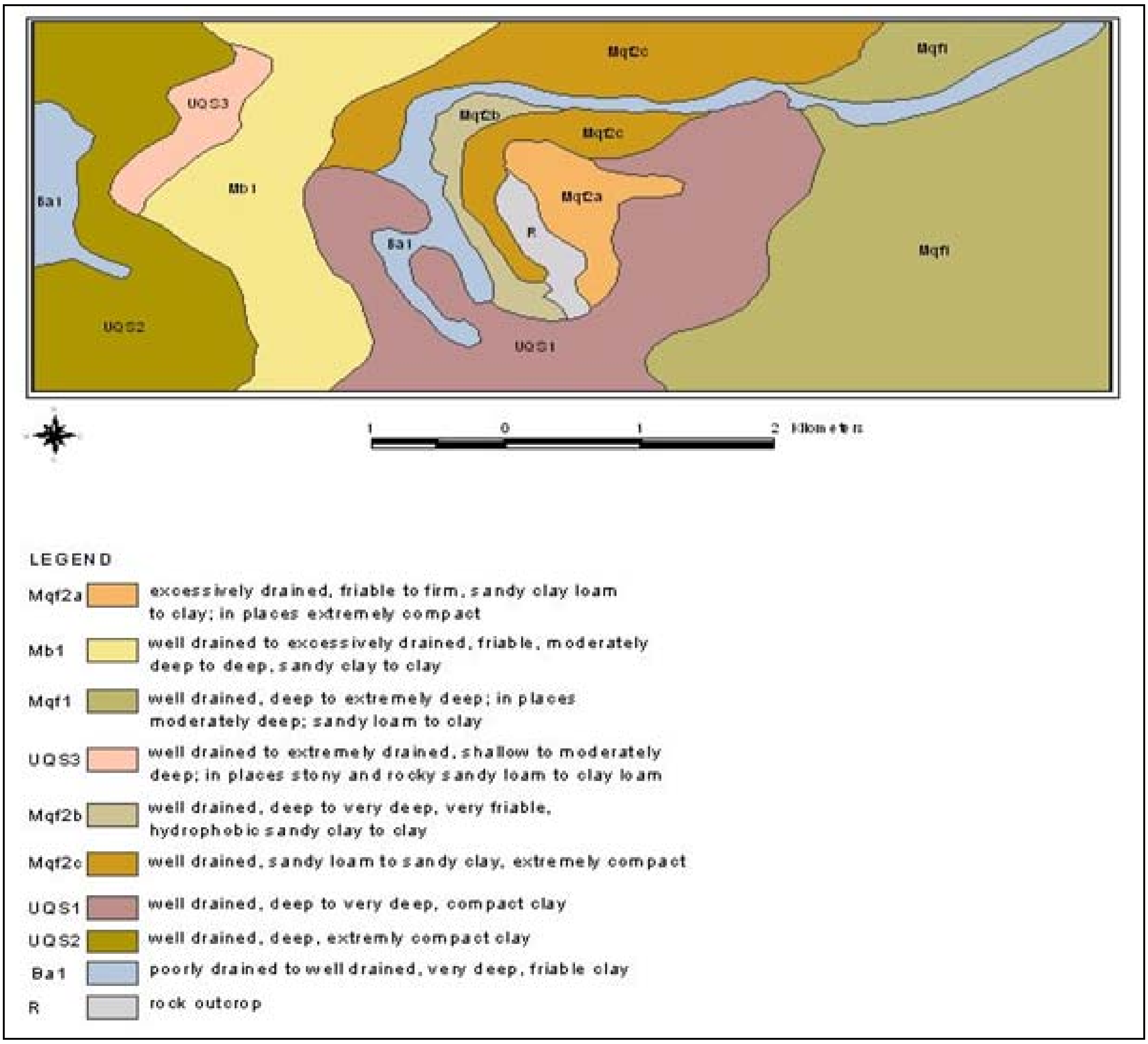

Figure 5b. Soil types in the Taita Taveta Benchmark Area.

CONCLUSIONS

The variation in soil characteristics under different land use types was found to be associated with changes in soil quality in relation to land use intensification gradients. The productivity index (PI) followed a similar trend, with the natural forest and grassland having the highest ratings and in horticultural and maize-based systems with the lowest .Thus decline in soil quality and productivity was linked to increased land use intensification, and these relationships can be used to explain the observed soil biodiversity trends. Lack of appropriate technologies and low human capacity of the farmers resulted in the negative impacts that the current soil management practices have on the environment. There were high correlations between the landuse types and soil quality which implies that those LUTs could be used as indicators of soil quality. For instance the high exchangeable soil acidity in forests and tea implied that high applications of organic matter or calcium are required to enhance availability of fixed nutrients such as K and P. The observed variations in soil properties would be expected to have an impact on the dynamics of soil organisms. This hypothesis is confirmed in the chapters that follow in this special issue.

Table 6: Comparative analysis of the bio-physical and soil characteristics of Embu and Taita benchmark areas.

Land characteristics	Embu site E1	E2	E3	Taita Taveta site T 1	T2
Main land use systems	Coffee and maize	Tea and maize	Natural forest, planted forest and tea	Maize, beans, potatoes and cassava	Maize, horticulture, natural forest, planted forest and coffee.
Geology	Tertiary, basic igneous rocks.	Tertiary, basic igneous rocks.	Tertiary, basic igneous rocks.	Undifferentiated Precambrian rocks.	Quartz-feldspar gneiss and felsic granulites.
Geomorphology	Lower level uplands, volcanic footridges and bottomlands.	Volcanic footridges.	Upper level uplands.	Upper level uplands.	Mountains, hills and footslopes.
Slope %	10-65	5-55	15-80	10-65	10-85
Altitude (m)	1200-1500	1200-1500	1500-2500	1200-1600	1600-2000
Mean minimum temperature °C	16-18	16-18	10-12	16-18	10-16
Mean maximum temperature °C	28-30	28-30	24-26	25-31	18-20
Mean annual rainfall (mm)	1400-1600	1400-1600	1800-2000	800-1000	1300-2000
General soil characteristics	Well drained, deep to extremely deep, reddish brown to dusky red.	Well drained, moderately deep to extremely deep, friable dark reddish brown to red clay.	Well drained, extremely deep, dark reddish brown to red, friable, smeary clay loam to clay.	Well drained, moderately deep to very deep, dark brown to dark reddish brown sandy clay loam to clay, in places gravelly.	Excessively drained to well drained, dark reddish brown to dark brown, shallow to extremely deep, friable to firm and compact sandy clay loam to clay, in places shallow, rocky and stony
Soil classification	Rhodic Nitisols and Humic Nitisols	Rhodic Nitisols	Humic Andosols	Haplic Acrisols and Eutric Cambisols	Chromic Luvisols, Eutric Cambisols and Regosols.

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