Journal of Agricultural Science and Technology A 4 (2014) 224-234
Earlier title: Journal of Agricultural Science and Technology, ISSN 1939-1250

Characterization of Some Typical Soils of the Miombo Woodland Ecosystem of Kitonga Forest Reserve, Iringa, Tanzania: Physico-Chemical Properties and Classification

Hassan Bashiru Shelukindo[1], Balthazar Msanya[1], Ernest Semu[1], Sibaway Mwango[1], Bal Ram Singh[2] and Pantaleo Munishi[3]

1. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro 3008, Tanzania

2. Department of Plant Science and Environment Studies, Norwegian University of Life Sciences, Ås1432, Norway

3. Department of Forest Biology, Faculty of Forestry and Nature Conservation, Sokoine University of Agriculture, Morogoro 3010, Tanzania

Received: November 11, 2013 / Published: March 20, 2014.

Abstract: Despite the fact that miombo woodland soils have significant implications in global climate change processes, few studies have been done to characterize and classify the soils of the miombo woodland ecosystem of Tanzania. The current study was carried out to map and classify soils of Kitonga Forest Reserve, which is a typical miombo woodland ecosystem, in order to generate relevant information for their use and management. A representative study area of 52 km^2 was selected and mapped at a scale of 1:50,000 on the basis of relief. Ten representative soil profiles were excavated and described using standard methods. Soil samples were taken from genetic soil horizons and analyzed in the laboratory for physico-chemical characteristics using standard methods. Using field and laboratory analytical data, the soils were classified according to the FAO-World Reference Base (FAO-WRB) for Soil Resources system as Cambisols, Leptosols and Fluvisols. In the USDA-NRCS Soil Taxonomy system the soils were classified as Inceptisols and Entisols. Topographical features played an important role in soil formation. The different soil types differed in physico-chemical properties, hence exhibit differences in their potentials, constraints and need specific management strategies. Texture varied from sandy to different loams; pH from 5.1 to 5.9; organic carbon from 0.9 g/kg to 20 g/kg; and CEC from 3 cmol/(+)kg to 24 cmol/(+)kg. Sustainable management of miombo woodlands ecosystem soils requires reduced deforestation and reduced land degradation.

Key words: Miombo woodlands, soil properties, soil classification, Kitonga Forest Reserve, Tanzania.

1. Introduction

The miombo[1] woodland ecosystem in Tanzania is found, among other places, in the Kitonga Forest Reserve (KFR) in Iringa Region. However, KFR has experienced extensive deforestation and degradation caused by human activities [1, 2]. Understanding the dominant soil types of the miombo woodland ecosystem in Tanzania and their physico-chemical properties would avail pertinent information for assessing the potentials and constraints of the soils for different uses and management options, thereby contributing to reduced disturbances, land degradation and improved climate change regulation.

Corresponding author: Hassan Bashiru Shelukindo, Ph.D. student, research field: evaluation of soil carbon storage in climate change scenario. E-mail: hbashelu@yahoo.com.

[1]Miombo Woodlands are typified by tree species belonging to family *Fabaceae*, subfamily *Caesalpinioideae*, and genera of *Brachystegia*, *Julbernadia* and *Isoberlinia*.

In Tanzania, the miombo woodlands cover about 32 million hectares or 93% of the total forested land area, or about 40% of total land area in the country [2, 3]. These woodlands provide diverse ecosystem services including wildlife sustenance, water catchment, fuel wood, fibre, charcoal, food, fodder, tourism, soil and water conservation, biodiversity, medicines, maintaining carbon stocks (and therefore regulating climate), controlling soil erosion, providing shade, modifying hydrological cycles and maintaining soil fertility all of which support livelihoods to adjacent communities [2-5]. Thus, in view of its huge areal coverage, classifying the soils according to their types and studying the physico-chemical properties of miombo woodland soils is of prime importance as this would clarify the potentials and constraints of the soils and lands in general, for various use and management packages.

Soils are known to vary greatly across landscapes, and are influenced by topographical features, vegetation types, lithology, climate and land use; and these may influence spatial and temporal variations in soil physico-chemical properties [6, 7]. Globally, the soils of the miombo woodland ecosystems are important in climate change processes [1, 8-10]. However, few studies have been undertaken to characterize and classify the soils of the miombo woodlands ecosystem in Tanzania [2, 7].

The major aim of the current study was to understand the dominant soil types in the miombo woodlands of KFR, with the following specific objectives:

- to map the soils and their spatial distribution over the study area;
- to characterize the soils based on the morphological field description and physico-chemical properties;
- to classify the soils using the World Reference Base (WRB) for Soil Resources [11] and the Natural Resources Conservation Services, United States Department of Agriculture (USDA-NRCS) using Soil Taxonomy system [12], to provide data for use by stakeholders in planning sustainable land management in miombo woodland.

2. Materials and Methods

The KFR (Fig. 1) is located in Kilolo District, Iringa Region, on the Northern and Southern sides of the Iringa-Morogoro road, at 07°35′-07°43′ S and 37°07′-37°10′ E, with altitude ranging from 660 m to 1,880 m above sea level. Rainfall data for the area are presented in Table 1, which shows that the mean annual rainfall is 594.32 mm, usually with no rain in June and July.

Table 2 presents temperature data, with temperatures ranging from 12 °C to 29 °C, with maximum temperatures in August to October (Tanzania Meteorological Agency, 2013).

The dominant vegetation types include the tree species *Brachystegia*, *Julbernardia* and *Diplorhynchus condylocarpon* spp.; grasses *Andropogon* and *Heteropogon* spp.; the shrub *Fadogia* spp. and the herb *Commelina africana* spp.. Severe deforestation and soil degradation were observed in the lower elevations.

3. Methodology

3.1 Field Methods

A free reconnaissance survey was carried out using transect walks, auger observations and descriptions in the field to identify major and representative landforms and soils. At each observation site, data on landform, soil morphological characteristics, elevation, slope gradient, parent material (lithology), vegetation and land use/crops were collected. From the reconnaissance survey, sites that represented major landforms and soils were selected along a transect running in a South-Eastward direction from Iringa municipality. In each identified landform unit, soil observations were made to a maximum depth of 1.5 m or to a limiting layer to identify soil properties by augering along the

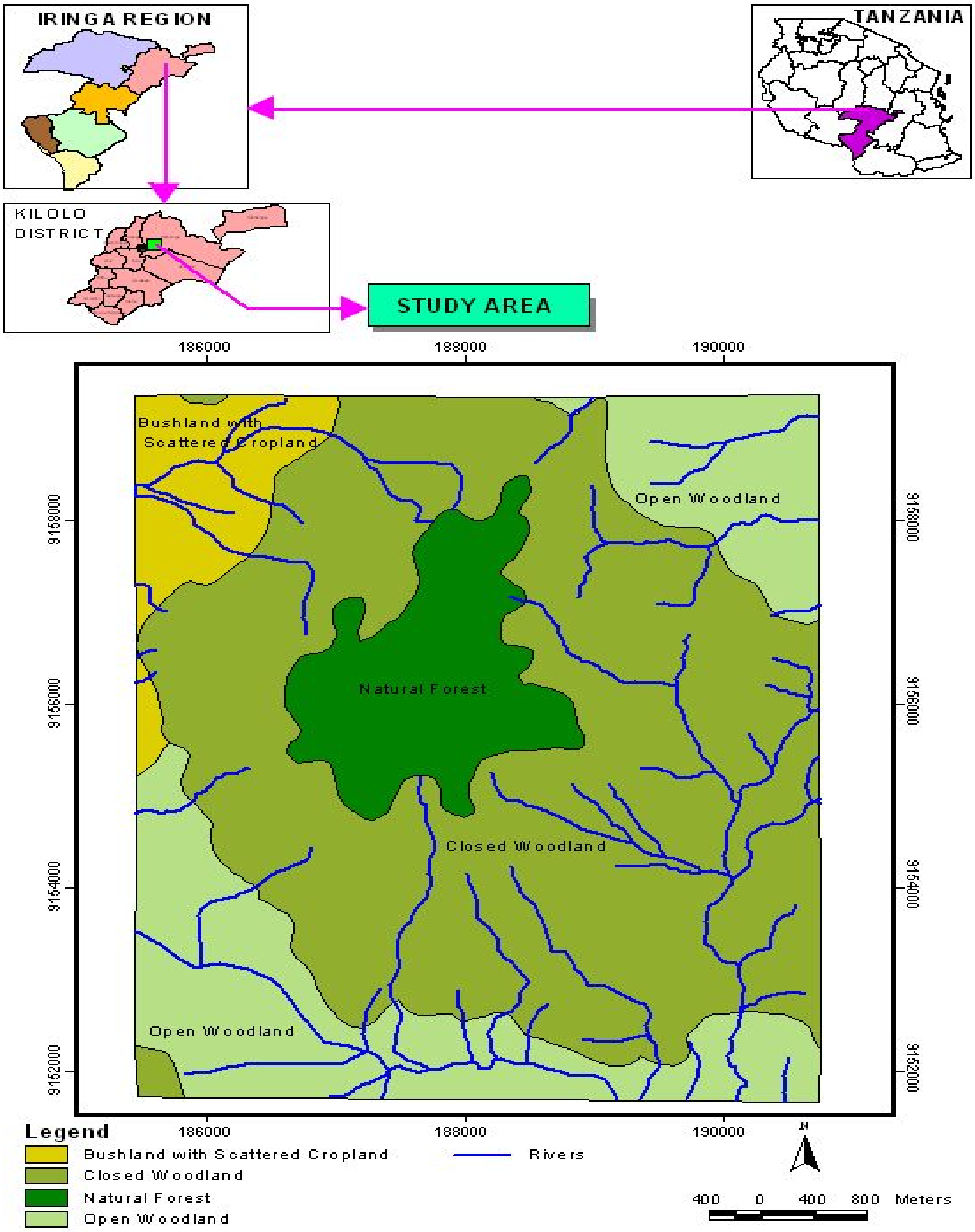

Fig. 1 Map of Tanzania showing study location.

transect. The sampling sites were geo-referenced using a Global Positioning System (GPS) (model OREGON 400t). These data were filled in forms adopted from the FAO guidelines for soil description [11]. In this study, ten representative soil profiles were dug and described according to FAO [11] guidelines, and samples taken from each pedogenic soil horizon for laboratory analysis.

3.2 Laboratory Methods

Soil samples were air-dried, ground and passed through a 2-mm sieve for laboratory analysis. Physical and chemical analyses were conducted as follows. Bulk density was determined using the core method [13], and texture was determined by the hydrometer method [14]. The pH was measured in water and 1 M

Table 1 Mean monthly rainfall (mm) in the study area from 1981-2012.

Month	mm
January	130.31
February	118.37
March	120.34
April	56.89
May	12.99
June	0.14
July	0
August	0
September	0.55
October	3.85
November	30.11
December	120.77
Mean annual rainfall	594.32

Source: Tanzania Meteorological Agency (2013).

Table 2 Mean monthly minimum and maximum temperatures (°C) in the study.

Month	Mean Min *T* (°C)	Mean Max *T* (°C)
January	16.30	26.44
February	15.90	26.51
March	15.51	26.80
April	15.39	26.38
May	14.43	26.14
June	12.68	25.28
July	12.01	24.59
August	12.34	25.50
September	13.20	27.29
October	14.69	28.69
November	15.94	29.12
December	16.51	27.66

Source: Tanzania Meteorological Agency (2013).

$CaCl_2$ at the ratio of 1:2.5 soil:water or soil:$CaCl_2$, respectively [15]. The 1 M $CaCl_2$ was used to predict presence of some salts such as sulphates or phosphates and other cations that might be found in the soil. Organic carbon was determined by the wet oxidation method [16]. Total N was determined using the micro-Kjeldahl digestion-distillation method as described by Bremner and Mulvaney [17]. Extractable phosphorus was determined using filtrates extracted by the Bray and Kurtz-1 method [18] and determined by spectrophotometer [19]. The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were determined by atomic absorption spectrophotometer [20]. The micronutrients Fe, Mn, Zn and Cu were extracted using buffered 0.005M DTPA (Diethylene triamine pentaacetic acid) (Lindsay and Norvell [21], and their concentrations determined by an Atomic Absorption Spectrophotometer (AAS) (UNICAM 919 model). The total exchangeable bases (TEB) were calculated arithmetically as the sum of the four exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) for a given soil sample.

3.3 Soil Classification

Based on the field and laboratory data, the soils were classified to tier-2 level of the FAO World Reference Base [10], and to subgroup level of the USDA-NRCS Soil Taxonomy.

4. Results and Discussion

4.1 Site Characteristics of the Study Area

The detailed site characteristics of the study area are presented in Table 3. Different slope forms were found in specific landform types, slopes, elevation gradient, soil moisture regimes and soil temperature regimes. Seibert et al. and Harter et al. [22, 23] described hill slope position, steepness, land shape and curvature as potential topographical features influencing soil formation and variation in soil physico-chemical properties of toposequences. The steeper the slope, the greater the influence topography has on soil development on hills and steep lands. Understanding these relationships could help in establishing a link between easily measured topographic parameters and some specific soil properties. Establishing such soil-landscape relationships should reduce the need for extensive field and laboratory testing but still provide reasonable data sets where such soil data are generally scarce. This improvement should help in formulating sustainable planning of land resources in the miombo woodland. The SMR showed increasing trend with increasing in elevation whereas the STR showed a decreasing trend with increasing in elevation. This trend has implications on variations in physico-chemical properties across elevation gradient including variation in OC. Similar results were reported in Refs. [22, 23].

Table 3 Salient features of the study area—Kitonga Forest Reserve.

Altitude (masl)	Location	Profile (No.)	Slope (gradient %)	Landform	Slope form	SMR*	STR**
831	36°9′0″ E 07°39′36″ S	5	25	Lower slope	Straight	Ustic	Thermic
928	36°11′24″ E 07°36′0″ S	3	15	V- Shaped Valley bottom	Concave	Aquic	Thermic
980	36°10′48″ E 07°39′33.66″ S	4	12	Ridge summit (Lower)	Convex	Ustic	Thermic
1,083	36°9′36″ E 07°39′0″ S	2	17	Ridge middle slope	Straight	Ustic	Thermic
1,241	36°9′36″ E 07°34′45″ S	8	10	U-Shaped Valley bottom	Concave	Aquic	Mesic
1,258	36°9′36″ E 07°35′24″ S	9	10	Foot slope	Straight	Ustic	Mesic
1,320	36°10′48″ E 07°38′24″ S	10	22	Ridge lower slope	Straight	Ustic	Mesic
1,377	36°9′36″ E 07°36′0″ S	7	25	Ridge middle slope	Straight	Ustic	Mesic
1,548	36°9′36″ E 07°38′24″ S	6	10	U-Shaped Valley bottom	Concave	Ustic	Mesic
1,598	36°10′12″ E 07°37′48″ S	1	1	Ridge summit	Convex	Ustic	Mesic

*SMR = soil moisture regime, **STR = soil temperature regime.

4.2 Soil Morphological Characteristics

The soil morphological characteristics are presented in Table 4. Most of the soils are brownish in colour, slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet, having moderate fine sub-angular blocky structure, common coarse and few medium pores, many fine and few coarse roots and clear wavy boundary. In the valleys most soils had mixed consistence with good drainage. The soil morphological characteristics of the studied profiles revealed varying horizon thicknesses within and between profiles. Hattar et al. [24] reported the soils differ in their horizons thickness, depending on the location along the toposequence.

4.3 Physical and Chemical Properties of the Soils

4.3.1 Soil Texture

Selected physical and chemical properties of the soils are presented in Table 5. The soils are well drained, dominantly coarse textured and varied from sand and sandy loam texture at the surface to sandy clay loam in sub-surface. The coarse textured soils with more than 65% sand and less than 18% clay usually have low fertility status. Studies conducted by Vågen & Winowieck [24] in Kenya (Dambidolo) and Tanzania (Mbinga), reported that sand contents control the variability of nutrient storage capacity of the soils. This is due to the fact that texture is a composite of the coarse fraction (sand) and the finer fractions (silt and clay), and increasing or decreasing one component imparts the opposite effect on the other and hence affects physico-chemical properties of the soils.

4.3.2 Soil pH

According to Baize [25], Euro Consult [26] and Landon [27], majority of the soils were rated as acidic, with mean pH value of 5.9 (medium), which is favourable for the growth of plants in mountainous and forest areas. Nearly all surface soils had lower pH values than those in the sub-soils, a trend which indicates leaching of exchangeable bases from surface to the sub-surface horizons. Delta pH (pH_{water}-pH_{Cacl2})

Table 4 Some morphological characteristics of profile soils.

Profile No.	Horizon	Depth (cm)	Moist colour[1]	Consistence[2]	Structure[3]	Horizon boundary[4]
1	Ah	0-15	db (7.5 YR3/3)	fr, ss & sp	mf, sbk	cw
	BA	15-32	yb (7.5 YR3/2)	fr, ss & sp	wf & m, sbk	gs
	Bw_1	32-57	rb (7.5 YR6/6)	vfr, ss & sp	wf & m, sbk	ds
	Bw_2	57-80	rb (7.5 YR5/6)	vfr, ss & sp	wf, sbk	ds
2	Ah	0-10	db (7.5 YR3/2)	fr, ss & sp	mf, sbk	cw
	Bw	10-25.0	dy (10 YR4/4)	fr, ss & sp	wf & m, sbk	gs
3	Ah	0-16	gb (10 YR3/2)	fr, ss & sp	mf, sbk	cw
	BA	16-33	b (10 YR3/3)	fr, ss & sp	mf & m, sbk	gs
	Bw	33-45	b (10 YR3/3)	fr, ss & sp	wf & m, sbk	ds
4	Ah	0-16	db (7.5 YR3/2)	fr, ss & sp	mf & m, sbk	cw
5	Ah	0-20	db (7.5 YR2.5/2)	fr, ss & sp	mf, sbk	cw
6	Ah	0-15	vdgb (10 YR3/2)	fm, ss & sp	mf, sbk	cw
	BA	15-27	vdgb (10 YR3/2)	fm, ss & sp	f & m, sbk	gs
	Bt1	27-45	db (10 YR3/3)	fm, ss & sp	f & m, sbk	ds
	Bt2	45-60	dg (10 YR4/1)	fm, ss & sp	wf, sbk	ds
	2BAb	60-100	vdg (10 YR4/1)	s, ss & sp	wf, sbk	ds
7	Ah	0-17	db (7.5 YR3/3)	fr, ss & sp	mf, sbk	cw
	Bt	17-35	dyb (10 YR4/4)	fr, ss & sp	wf & m, sbk	gs
8	Ah	0-19	vdb (7.5 YR2.5/3)	fr, ss & sp	mf, sbk	cw
	2Bgb1	39-72	b (7.5 YR5/3)	fr, ss & sp	wf & m, sbk	ds
	2Bgb2	72-130	b (7.5 YR5/3)	fr, ss & sp	wf, sbk	ds
9	Ah	0-10	db (7.5 YR3/2)	fr, ns & np	mf, sbk	cw
	Bw	10-25.0	b (7.5 YR5/2)	fr, ss & sp	wf & m, sbk	gs
	BC	25-45	b (7.5 YR5/2)	fr, ss & sp	f & m, sbk	ds
10	Ah	0-17	db (7.5 YR3/3)	fr, ss & sp	mf, sbk	cw
	Bt	17-35	dyb (10 YR4/4)	fr, ss & sp	sbk	gs

[1]db = dark brown; yb = yellowish brown; rb = reddish brown; dy = dark yellow; gb = greyish brown; b = brown; vdgb = very dark greyish brown; dg = dark grey; vdg = very dark grey; dyb = dark yellowish brown; vdb = very dark brown;
[2]vfr = very friable; fr = friable; s = sticky; ss = slightly sticky; sp = slightly plastic; ns = nonsticky; np = nonplastic; fm = firm;
[3]mf = moderate fine; sbk = subangular blocky; wf = weak fine; medium; f = fine;
[4]cw = clear wavy; gs = gradual smooth; ds = diffuse smooth.

values in all KFR profiles were positive. This tendency indicates that the exchange complex of the colloidal fractions of the soils is mostly negatively charged [28].

4.3.3 Organic Carbon (OC) and Total Nitrogen (N)

From the results (Table 5), the surface soils of KFR were low in OC content, with the exception of profile number 5 which had very high organic carbon in the surface horizon. The soils presented by profile No. 5 occupy the areas which showed evidence of soil sedimentation following land degradation and erosion uphill. Recent sedimentation may have increased the soil moisture at the surface layer, due to the OC contained in the deposited sediments. Studies [29, 30], conducted in China and Germany, respectively, reported SOC stocks to be influenced more by soil moisture. The levels of organic carbon in the sub-soils were very low to high, with the exception of soils of profile No. 1 which had sub-soils with relatively higher organic carbon than the upper horizons. This could be contributed by the high bulk density of this sub surface horizon compared to those in the upper horizons. Aticho [31] reported that bulk density and horizon thickness influence organic carbon accumulation.

Most of the surface soils had low N levels, with very low N contents in all sub-soils. There was a positive correlation between organic carbon and total nitrogen. This trend was also found by others [32].

Table 5 Selected physico-chemical properties of soils of Kitonga Forest Reserve.

Profile No.	Horizon	Depth (cm)	pH		Soil separates g/kg			Text.	BD	OC g/kg	OM g/kg	% N	mg/kg	Bases and CEC (cmol(+)/kg)				
			H_2O	$CaCl_2$	Clay	Silt	Sand	*Class	gc-3				Av. P	Ca	Mg	Na	K	CEC-NH_4OAc
1	Ah	0-15	5.2	4	340	90	570	SCL	1.08	4.2	7.3	0.03	0.62	0.48	0.5	0.23	0.43	6.6
	BA	15- 32	5.5	4.3	340	70	590	SCL	1.16	1.7	2.9	0.02	0.5	0.53	0.46	0.22	0.36	6
	Bw_1	32- 57	5. 6	4.7	304	66	630	SCL	1.04	1.5	2.6	0.01	0.39	0.63	0.45	0.2	0.29	6.6
	BW_2	57- 80	6.7	6.2	144	46	810	SL	1.22	15.7	27.2	0.11	28.89	4.96	2.2	0.2	0.36	10.4
2	Ah	0- 10	5.9	4.9	224	46	730	SCL	1	6.2	10.7	0.06	2.3	1.31	2.95	0.26	0.31	6.4
	Bw	10- 25.0	5.2	4.7	104	46	850	LS	1.1	20	34.6	0.13	9.5	3.04	1.44	0.21	0.27	9
3	Ah	0- 16	5.1	4.4	104	46	850	LS	1.14	4	6.9	0.4	0.5	0.4	1.17	0.16	0.14	5.8
	BA	16- 33	5.3	4.4	103	27	870	LS	1.1	2	3.5	0.1	0.17	0.48	1.19	0.17	0.14	4.4
	Bw	33- 45	6.4	5.8	103	47	850	LS	1.11	12.5	21.7	0.1	19	3.42	1.13	0.17	0.46	9
4	Ah	0- 16	5.4	4.6	143	67	790	SL	1.31	12.5	21.7	0.11	6.7	1.69	2.8	0.19	0.46	10
5	Ah	0- 20	6.8	6.2	243	127	630	SCL	1.21	44	76.2	0.25	3.14	10.7	3	0.33	0.52	24
6	Ah	0- 15	6.2	5.9	263	106	631	SCL	1.23	21	36.4	0.17	1.4	5.2	2.4	0.3	0.3	16.6
	BA	15- 27	6.2	4.8	203	46	751	SCL	1.31	14	24.2	0.08	0.5	2.5	1.3	0.3	0.2	9.4
	Bt1	27- 45	6	4.8	243	26	731	SCL	1.3	13	22.5	0.05	0.84	2.7	1.3	0.3	0.1	9.2
	Bt2	45- 60	5.5	4.4	283	46	671	SCL	1.21	11.7	20.3	0.06	0.84	3	1.6	0.4	0.3	9.4
	2BAb	60- 100	5.9	4.4	123	86	791	SL	1.17	15.5	26.8	0.08	19.7	3.4	1.5	0.2	0.2	8.2
7	Ah	0- 17	5.1	4.1	123	86	791	SL	1.21	4.4	7.6	0.03	7.4	2.5	0.9	0.2	0.2	8.6
	Bt	17- 35	6.1	4.4	283	46	671	SCL	1.26	16.2	28.1	0.18	1	2.9	1.1	0.7	0.3	13.2
8	Ah	0-19	6	4.2	84	46	870	S	1.09	11.2	19.4	0.1	0.3	1.5	0.6	0.4	0.2	8.4
	Bw	19-39	6.9	4.4	63	06	931	S	1.11	1.7	2.9	0.01	5.8	0.7	0.3	0.4	0.2	4
	2Bgb1	39-72	6.2	4.5	63	06	931	LS	1.1	0.9	1.6	0.01	2.6	0.6	0.2	0.2	0.1	3
	2Bgb2	72- 130	5.4	4.4	103	26	871	LS	1.12	13.9	24.1	0.07	2.4	0.7	0.8	0.2	0.3	7.4
9	Ah	0- 10	6.1	4.4	103	46	851	LS	1.12	4	6.9	0.04	2.1	0.4	0.6	0.2	0.2	4.8
	Bw	10- 25.0	5.9	4.2	83	26	891	LS	1.2	3	5.2	0.01	0.4	1.5	0.3	0.2	0.2	3.4
	BC	25- 45	6.2	4.3	163	46	791	SL	1.2	13	22.5	0.08	1.1	1.5	0.6	0.4	0.1	8.6
10	Ah	0- 17	5.1	4.1	123	86	791	SL	1.2	4.4	7.6	0.03	7.4	2.5	0.9	0.2	0.2	8.6
	Bt	17-35	6.1	4.4	283	46	671	SCL	1.26	16.2	28.1	0.18	1	2.9	1.1	0.7	0.3	13.2

* SCL = sand clay loam; SL = sandy loam; S = sandy; LS = loamy sand.

4.4 Cation Exchange Capacity, Potassium, Sodium, Calcium and Magnesium

4.4.1 Cation Exchange Capacity (CEC)

CEC is a measure of the capacity of soil to retain nutrients (against leaching) [32]. The top surface of KFR had low values of CEC and relatively lower CEC values in the sub-soils than those of the surface-soils, except profile 7 which had relatively high CEC in the sub-surface horizon. This might have been contributed by movement into and accumulation of clay in the sub-surface horizon. The CEC usually gives an idea of the potential fertility of the soil. London [27] reported ranges between 15 cmol(+)/kg to 25 cmol(+)/kg to be satisfactory for growth of most plants. The results from the present study indicate very low to medium (2.4-24 cmol(+)/kg) levels of CEC.

The levels of K and Na were low both in the surface and the sub-soils, whereas the levels of Ca and Mg in the surface soils ranged from very low to very high, with medium average levels.

Generally, the miombo woodland soils in the study area indicated inherently low soil fertility status, which could be attributed to the nature of parent materials, modes of formation coupled with frequent fires, grazing, charcoal burning and continued deforestation of the miombo woodland ecosystem.

Nshubemuki and Mbwambo [2], Frost [33], observed a similar trend in the soils of miombo woodlands in Tabora (Tanzania), which are inherently poor in nutrients but with wide variation in fertility status.

4.4.2 Phosphorus, Calcium and Magnesium

The soils of KFR had medium levels of phosphorus (P), calcium (Ca) and magnesium (Mg), which according to Landon [28], are adequate for supporting plant growth.

4.5 Soil Types and Their Relationship to Topography

The detailed classification of soils representative of the mapping units of Kitonga Forest Reserve is shown in Table 6, and the soil map showing the areal distribution of the soil types is shown in Fig. 2. The soils were classified as Cambisols, Leptosols and Fluvisols [9] or Inceptisols and Entisols [10]. Different soil types were found under specific topographic features. Cambisols (Inceptisols) were found on ridge summit slopes with convex slopes, Fluvisols (Entisols) on U- and V-shaped valley bottoms with concave slopes, and Leptosols on ridge middle slopes with straight slopes (Table 3). This elucidates the relationship between landforms and soil formation. The findings agreed with those Aticho [32] that topographic features affect the physical and chemical properties of soils.

4.6 Soil Mapping Units

Table 7 gives a summary of the mapping units and the areal coverage of those dominant soil types. The distribution was Cambisols (61%) covering 31 km^2 > Leptosols (19%) covering 10 km^2 and > Fluvisols (11%) covering 6 km^2. Variation in aerial coverage of these soil types explains to a great extent variation in physico-chemical properties of the study area. Thus, detailed studies of those soils in terms of carbon storage are necessary in order to explore their contribution to global climate change processes.

5. Conclusions

Leptosols, Fluvisols and Cambisols were identified as the dominant soil types according to the FAO system, which were equivalent to Entisols and Inceptisols in the USDA-NRCS Soil Taxonomy system. Those soil types differed in physico-chemical properties, hence exhibit differences in their potentials and constraints for different uses. Proper management of Cambisol (Inceptisol) soil type which occupied relatively large area would have substantial positive impact on the Kitonga catchment forest reserve. Different soil types were found under specific topographic features. This confirmed the relationship between landforms and soil formation. Cambisols (Inceptisols) occupied a relatively large area (61%) of the studied area, compared to the other soil types. The large aerial coverage of Cambisols (Inceptisols) would have implications in nutrient storage capacity, management and use. Miombo woodlands in the study

Table 6 Classification of the soils of Kitonga Forest Reserve.

FAO-WRB					USDA-NRCS Soil Taxonomy			
Profile No.	Reference soil groups (RSGs)	Prefix qualifier (s)	Suffix qualifier (s)	Tier-2 soil names	Order	Suborder	Greatgroup	Subgroup
1	Cambisol	Ferralic	Epidystric, Chromic	Ferralic Cambisol (Epidystric, Chromic)	Inceptisol	Ustep	Drystrustept	Oxic Dystrustept
2	Leptosol	Cambic	Eutric	Cambic Leptosol (Eutric)	Entisol	Orthent	Ustorthent	Lithic Orthent
3	Fluvisol	Fluvic, Haplic	Dystric	Haplic Fluvic, Fluvisol (Dystric)	Entisol	Psamment	Ustipsamment	Lithic Ustipsamment
4	Leptosol	Cambic	Eutric	Cambic Leptosol (Eutric)	Entisol	Orthent	Ustorthent	Lithic Ustorthent
5	Leptosol	Mollic	Humic, Eutric	Mollic Leptosol (Humic, Eutric)	Entisol	Orthent	Ustorthent	Lithic Ustorthent
6	Fluvisol	Stagnic, Umbric	Endoeutric, Humic	Umbric Stagnic Fluvisol (Endoeutric, Humic)	Entisol	Fluvent	Usticfluvent	Oxyaquic Usticfluvent
7	Cambisol	Ferralic	Dystric	Ferralic Cambisol (Dystric)	Inceptisol	Ustept	Drystrustept	Oxic Dystrustept
8	Fluvisol	Fluvic, Stagnic	Dystric, Chromic	Stagnic Fluvic Fluvisol (Dystric, Chromic)	Entisol	Fluvent	Usticfluvent	Oxyaquic Ustifluvent
9	Cambisol	Haplic	Eutric	Haplic Cambisol (Chromic, Eutric)	Inceptisol	Ustept	Drystrustept	Typic Dystrustept
10	Cambisol	Ferralic	Eutric	Ferralic Cambisol (Eutric)	Inceptisol	Ustept	Drystrustept	Oxic Dystrustept

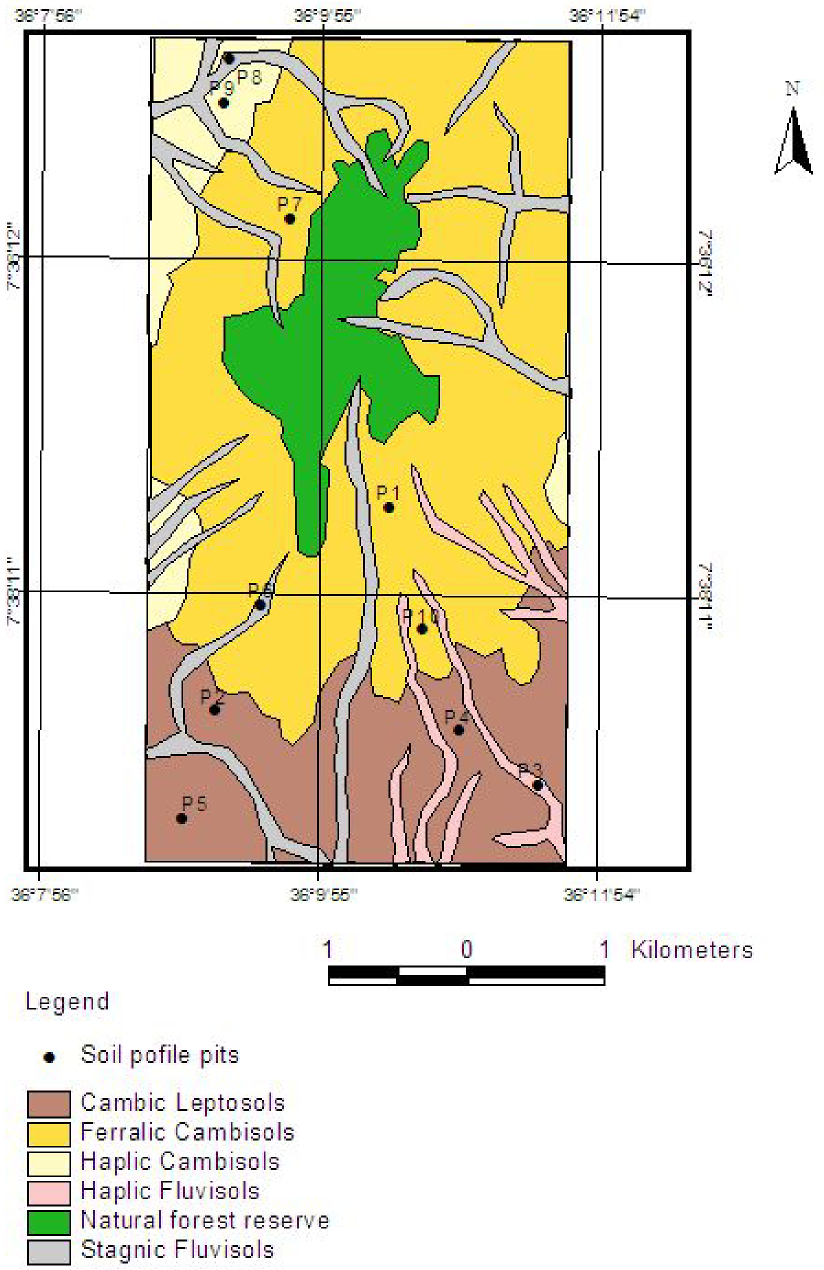

Fig. 2 Soil map of miombo woodland-Kitonga Forest Reserve.

Table 7 Summary of soil mapping units and their areal extent, Kitonga Forest Reserve.

Soil mapping units (SMUs)	Soil types (FAO-WRB, 2006)	Areal extent of SMUs in ha	% distribution
SF	Stagnic Fluvisol	404	7.8
HF	Haplic Fluvisol	167	3.2
HC	Haplic Cambisol	330	6.4
CL	Cambic Leptosol	992	19.0
FC	Ferralic Cambisol	2,816	54.6
NR	Natural reserve (not described because of inaccessibility)	463	9.0
Total area		5,172	100.0

area were dominated by soils with low levels of nutrient elements due to wild fires, grazing, charcoal burning, deforestation, which exacerbated soil erosion.

6. Recommendations

From the results of this study, the following recommendations are given.

Specific land management and conservation strategies should be devised for each soil type due to variations in the physico-chemical properties of each soil type.

Sustainable conservation and management strategies in general for the miombo woodlands in Tanzania should be devised to avoid forest fires, grazing, charcoal burning, deforestation and cultivation, as adaptation and mitigation measures to insure sustainable provision of ecosystem services to surrounding communities.

Further research should be done to explore the potential of those soil types in climate change regulation.

Acknowledgments

The authors are thankful for the financial support provided to the senior author by the Climate Change Impacts Adaptation and Mitigation Measures (CCIAM) Project, Sokoine University of Agriculture, under the research title “quantification and mapping of carbon stocks and plant diversity in different land cover types in Tanzania” which enabled the senior author to undertake this study.

References

[1] D.D. Shirima, P.K.T. Munishi, S.L. Lewis, N.D. Burgess, A.R. Marshall, A. Balmford, et al., Carbon storage, structure and composition of miombo woodlands in Tanzania’s Eastern Arc Mountains, African Journal of Ecology 49 (2011) 332-342.

[2] L. Nshubemuki, L. Mbwambo, Trees to promote in the management of miombo woodlands in Tanzania: Species, sizes and qualities, in: M. Varmola, S. Valkonen, S. Tapaninen (Eds.), MITMIOMBO-Management of Indigenous Tree Species for Ecosystem Restoration and Wood Production in Semi-Arid Miombo Woodlands in Eastern Africa, Proceedings of the First MITMIOMBO Project Workshop held in Morogoro, Tanzania, Working Papers of the Finnish Forest Research Institute, No. 50, 2007.

[3] FAO, State of World’s Forests, Food and Agriculture Organization of the United Nations, Rome, 2009, p. 168.

[4] P.A. Dewees, B.M. Campbell, Y. Katerere, A. Sitoe, A.B. Cunningham, A. Angelsen, et al., Managing the Miombo woodlands of southern Africa: Policies, incentives and options for the rural poor, J. Nat. Resour. Policy Res. 2 (2010) 57-73.

[5] E. Woollen, R.M. Casey, W. Mathew, Carbon stocks in an African woodland landscape: Spatial distribution and scales of variation, Journal of Ecosystems 15 (2012) 804-818.

[6] M. Fantappiè, M.G. L’Abate, E.A.C. Costantini, The influence of climate change on the soil organic carbon content in Italy from 1961 to 2008, Geomorphology 135 (2011) 343-352.

[7] B.M. Msanya, A.K. Kaaya, S. Araki, H. Otsuka, G.I. Nyadzi, Pedological characteristics, general fertility and classification of some benchmark soils of morogoro district, Tanzania, African Journal of Science and Technology (AJST) Science and Engineering Series 4 (2) (2003) 101-112.

[8] P.K.T. Munishi, R.P.C. Temu, G. Soka, Plant communities and tree species associations in a Miombo ecosystem in the Lake Rukwa basin, Southern Tanzania: Implications for conservation, Journal of Ecology and the Natural Environment 3 (2) (2011) 63-71.

[9] W.A. Mugasha, E. Tron, O.M. Bollandsås, R.E. Malimbwi, S.A.O. Chamshama, E. Zahabu, et al., Allometric models for prediction of above- and below-ground biomass of trees in the miombo woodlands of Tanzania, Forest Ecology and Management 310 (2013) 87-101.

[10] R.A. Giliba, E.K. Boon, J.C. Kayombo, L.I. Chirenje, E.B. Musamba, The influence of socio-economic factors on deforestation: A case study of the bereku forest reserve in Tanzania, J. Biodiversity 2 (1) (2011) 31-39.

[11] FAO-WRB, World reference base for soil resource, A framework for international classification, correlation and communication, World Soil Resources Reports 103 (2006) 145-159.

[12] Soil Survey Staff, Keys to Soil Taxonomy, United State Department of Agriculture, 11th ed., Natural Resource Conservation Service, 2010, p. 346.

[13] G.R. Black, K.H. Hartge, Bulk density, in: Methods of Soil Analysis, American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, No. 9, 1986, pp. 364-376.

[14] P.R. Day, Particle fractionation and particle size analysis, in: C.A. Black, D.D. Evans, J.L. White, L.E. Ensminger, F.E. Clark (Eds.), Methods of Soil Analysis: Physical and Mineralogical Methods, American Society of Agronomy, Madison, Wisconsin, 1965, pp. 545-566.

[15] E.O. McLean, Soil pH and lime requirement, in: Methods of Soil Analysis, American Society of Agronomy and Soil Science Society of America, Madison, Wiscon, Chemical and Mineralogical Properties, No. 9, 1986, pp. 199-223.

[16] D.W. Nelson, L.E. Sommers, Total carbon, organic carbon and organic matter, in: Methods of Soil Analysis, American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, No. 9, 1982, pp. 539-579.

[17] J.M. Bremner, C.S. Mulvaney, Total nitrogen, in: Methods of Soil Analysis, American Society of Agronomy, Madison, Wisconsin, No. 9, 1982, pp. 595-624.

[18] R.H. Bray, L.T. Kurtz, Determination of total organic and available forms of phosphorus in soils, Soil Science 59 (1945) 39-45.

[19] F.S. Watanabe, S.R. Olsen, Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil, Soil Science Society of America Proceedings 29 (1965) 677-678.

[20] G.W. Thomas, Exchangeable cations, in: Chemical and Mineralogical Properties, Agronomy Monograph, No. 9, 1982, pp. 595-624.

[21] W.L. Lindsay, W.A. Norvell, Development of DTPA soil test for Zn, Fe, Mn and Cu, Soil Science Society of American Journal 42 (1978) 421-428.

[22] J. Seibert, J. Stendahl, R. Sørensen, Topographical influences on soil properties in boreal forests, Geoderma 141 (2007) 139-148.

[23] B.I. Hattar, A.Y. Taimeh, F.M. Ziadat, Variation in soil chemical properties along toposequences in an arid region of the Levant, Catena 83 (2010) 34-45.

[24] T.G. Vågen, L.A. Winowieck, Mapping of soil organic carbon stocks for spatially explicit assessments of climate change mitigation potential, Environmental Research Letters 8 (2012) 9-10.

[25] D. Baize, Soil Science Analysis: A Guide to Correct Use, John Wiley and Sons Ltd., West Sussex, 1993, p. 192.

[26] EuroConsult, Agriculture Compendium for Rural Development in the Tropics and Sub Tropics, 3rd ed., Elsevier, Amsterdam, Oxford, New York, Tokyo, 1989, p. 740.

[27] J.R. Landon, Booker Tropical Soil Manual, A handbook for soil survey and agricultural land evaluation in the tropics and subtropics, Longman Scientific & Technical Publishers, Essex, 1991, p. 474.

[28] H.J. Bohn, B.L. McNeal, G.A. O'Connor, Soil Chemistry, 2nd ed., Wiley Interscience Publication, New York, 1985, p. 341.

[29] W. Liu, S. Chen, X. Qin, F. Baumann, T. Scholten, Z. Zhou, et al., Storage patterns, and control of soil organic carbon and nitrogen in the northeastern margin of the Qinghai-Tibetan Plateau, Journal of Environmental Research Letters 7 (2012) 12.

[30] M. Wiesmeier, S. Peter, G. Uwe, H. Edzard, H. Stephan, R. Arthur, et al., Soil organic carbon stocks in southeast Germany (Bavaria) as affected by land use, soil type and sampling depth, Global Change Biology 10 (2012) 1365-2486.

[31] A. Aticho, Evaluating organic carbon storage capacity of forest soil: Case study in Kafa Zone Bita District, Southwestern Ethiopia, American Eurasian Journal Agriculture Environmental Science 13 (1) (2013) 95-100.

[32] B.M. Msanya, D.N. Kimaro, G.G. Kimbi, E.P. Kileo, J.D.J. Mbogoni, Land resources inventory and suitability assessment for the major land use types in Morogoro Urban District, Tanzania, in: Soils and Land Resources of Morogoro Rural and Urban Districts, Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania, ISBN 9987 605 29 X, 2001.

[33] P. Frost, The ecology of miombo woodlands, in: B.M. Campbell (Ed.), The Miombo in Transition: Woodlands and Welfare in Africa, Center for International Forestry Research, Bogor, Indonesia, 1996, pp. 11-57.