Original Research Article

Effect of Altitudinal Gradient and Selected Land-use Systems on the Physicochemical Properties of Soils in the Eastern Flank of Mount Cameroon

ABSTRACT

The physicochemical properties of soils within the Mount Cameroon region are constantly changing due to their altitudinal gradient and diverse land-use systems. This modification poses a threat to the inhabitants of this area as their livelihood depends on these soils. Information about an impact of altitude and land-use systems on soil physicochemical properties in the eastern flank of Mount Cameroon is scanty and needs further investigation. Soil samples, collected from different land-use systems along altitudinal gradients within the Buea zone (older lava flow) and Ekona zone (20th century lava flow), were analysed for their physicochemical properties using standard methods. The relationships among soil properties; altitude and land-use systems were established using correlation analysis and the analysis of variance (ANOVA). Sand and clay varied significantly ($p<0.05$) with altitude. Soils under mixed cropping with legumes had the highest pH values while those under mixed cropping without legumes had the lowest pH values. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) dominated the exchange complex. Total nitrogen (N) and organic carbon (OC) ranged from 0.18 % and 1.50 %, respectively in soils under mixed cropping without legumes to 0.81 % and 6.55 %, respectively in soils under fallow land. There were significant ($p<0.05$) positive correlations between pH and Ca^{2+}, pH and effective cation exchange capacity (ECEC), pH and moisture content (MC), and Ca^{2+} and MC. Soils from the Ekona zone located at the leeward side of the mountain and receiving more essential nutrients from the weathering of the young lava flow had a better-quality potential compared to soils from the Buea zone located at the foot of an older lava flow. The Ekona zone could be harnessed for extensive agricultural activities. Management practices should therefore take into account all cultural practices, which enrich soils for sustainable crop production and soil maintenance.

Keywords: *Soil physicochemical properties, land-use systems, altitude, Mount Cameroon*

1. Introduction

The rate of soil degradation depends on land-use systems, soil types, topography, high population pressure, inappropriate agricultural practices, massive deforestation of natural forest (farm expansion, fuel, and construction), agricultural expansion (cultivation of steep slopes and marginal areas), rugged nature of the landscape, biological properties and management strategies (Sanchez, 2002; Gebeyaw, 2015; Selassie et al., 2015; Sarvade et al., 2016a; Mengistu et al., 2017; Elias, 2019; Guadie et al., 2020). Aluko and Fagbenro (2000) observed high pH and organic matter for soils under *Gmelina aborea* than those under *Pinus canaborea, Treculia africana*, agroforestry and fallow. They observed high phosphorus (P) in fallow compared to other land-use systems. Weldemariam et al. (2020) found increased nutrient mining, soil erosion, and limited nutrient management which leds to declining soil quality and productivity in many parts of Ethiopia, which is more pronounced in highly rugged agrarian landscapes where land use influences and topographic variation dominate. Furthermore, Akamigbo and Asadu (2001) reported marked changes in soil morphological, physical and chemical properties, which resulted to accelerated pedogenic processes, and a decline in fertility of soils under traditional farming than forestland. Goi (2014) reported that the long-term cultivation of soils in the Dagdami river catchment in Turkey significantly ($p<0.05$) decreased the Soil Organic Matter content. Yerima and Van Ranst (2005) reported that the physical and chemical properties of Andosols in Cameroon were significantly affected by the management strategies and crops under cultivation (*Theobroma cocoa, Carica papaya* etc). Tellen and Yerima, (2018) similarly reported significant effect of eucalyptus on soil physicochemical properties in the North West region of Cameroon. Tening et al. (1995) showed that continuous cropping on sub humid soils greatly reduced crop yield and potassium uptake when no fertilizer was applied. Therefore, soils have potential (more or less) to support different land-use systems.

The success in soil management to maintain soil quality depends on an understanding on how soils respond to agricultural practices over time (Gebeyaw, 2015). For this reason, recent interest in evaluating soil quality has been stimulated by increasing awareness that the soil is a critical important component of the earth's biosphere, functioning not only in the production of food and fibre but also in the maintenance of local, regional and worldwide environmental quality (Oloade et al., 2010; Yao et al., 2010, Sarvade et al., 2017; Miheretu and Yimer, 2018).

The eastern flank of mount Cameroon is one of the areas of increasing human activities as a result of the increase in population over the years. These activities, together with natural processes, alter the soil colloids, which eventually will affect the soil's capacity to retain hazardous substances dumped into the environment through surface or land filling. The contribution by rural farmers, particularly women, in protecting these soil colloids through different land-use systems is a vital first step in recognising the role played by the rural farmer in sustainable management of the fragile tropical environment. Information on the effect of land-use systems on soil quality, to give recommendations for optimal and sustainable utilizations for the existing land is scanty. The purpose of this work was to provide information on the sustainability of agricultural land-use systems on soil quality in the eastern flank of mount Cameroon.

2. Materials and methods

The study area is situated between 300 and 1000 m above sea level (m a.s.l) (Figure 1). The area is made up of the Buea zone (latitudes 04°09.323'N and 04°08.750'N; longitudes 009°14.425'E and 009°18.264'E) and the Ekona zone (latitudes 04°13.572'N and 04°13.818'N; longitudes 009°19.449'E and 009°19.709'E). The Buea zone is on the windward side of mount

Cameroon with a mean annual rainfall of 2156 mm (Tening et al*.,* 2011) while the Ekona zone is on the leeward side of the mountain with a mean annual rainfall of 1618 mm (Fonge et al*.,* 2011). The farming operations in the study area were both mechanised by Cameroon Development Corporation (CDC) and subsistence by the rural farmers. The latter was chosen for this exercise because the majority of the farming activities in this area as in other developing countries are carried out by rural farmers (Finda, 2009). An information on agricultural land-use systems commonly practiced in this area by the farmers was collected using open questionnaires. Mixed cropping without legumes, mixed cropping with legumes, sole cropping and fallow were the common land-use systems in the study area (Table 1). Soil samples were collected from the different land-use systems following altitudinal gradient. Sampling points were established using the Global Positioning System (GPS. The moist soil colours were determined using the Munsell soil colour charts (Munsell, 2000).

Sixteen surface (0-20 cm) soil samples were collected in two sets from the study area. The fresh weights of one set were recorded for moisture content determination at 105^{o}C. The samples of the second set (of this set, under each land use, four subsamples were collected and then bulked) were air-dried and grind to pass through a 2-mm sieve. Particle size distribution was determined by the hydrometer method (Gee and Or, 2002). Moisture content (MC) was determined using the gravimetric method (Klute, 1982).

The soil pH was measured potentiometrically, in distilled water using a soil to extraction solution ratio of 1:2.5 (w/v) (IITA, 1979). Total nitrogen (Tot. N) and organic carbon (OC) were determined by the Kjeldahl and Walkley-Black wet oxidation methods, respectively (Tchuenteu and Schalk, 1988). Available phosphorus (Avail. P) was extracted by Bray-1 procedure and determined using the molybdate blue procedure described by Murphy and Riley (1962). Measurements for P were made at 885 nm on a Philips Pyre Unicam uv/vis spectrophotometer.

Exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and sodium (Na^{+}) were extracted using one normal ammonium acetate solution (pH 7) (Thomas, 1982). Exchangeable aluminium (Al^{3+}) was extracted using 1M KCl (Barnhisel and Bertsch, 1982) and determined using the pyrocatechol violet method. The ECEC was calculated as the sum of the exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) and exchange Al^{3+} (Tchuenteu and Schalk, 1988).

The statistical package from social science (SPSS-17) and Excel-2007 tools were used for the analysis of the data. Soil data was subjected to correlation analysis to establish the relationship between soil properties. The relationships among soil properties, altitude and the land-use systems were established using the analysis of variance (ANOVA) in which treatment means were compared with Fisher's protected LSD ($p<0.05$).

3. RESULTS AND DISCUSSION

3.1 Physicochemical properties of soils under different land-use systems

Soil colour ranged from dark yellowish brown to very dark greyish brown (Table 1). Soils under mixed cropping without legumes and sole cropping had colours ranging from dark reddish brown (5YR 3/3) to brown (7.5YR 4/4) and dark yellowish brown (10YR 4/4) to dark brown (10YR 3/3), respectively. Soil colour under mixed cropping with legumes and fallow land ranged from strong brown (7.5YR 4/6) to very dark brown (7.5YR 2.5/3) which could be reflecting higher organic matter content, relative to soils under mixed cropping without legumes and sole cropping. Soil colour gives an indication of organic matter and chemical constituents of soils (Munsell, 2000).

The particle size distribution of the soils under the different land-use systems is shown in Table 2. The soils under the different land-use systems ranged from sandy loam (altitude 880-938 m) to clay (altitude 542-784 m) in the Buea zone. Those of the Ekona zone were sandy loam (altitude 398-412 m). This finding corroborates the report of Amusan et al. (2006) that soil properties also varied with altitude. In a study in the Warandhab Area in Ethopia, Mengistu et al. (2017) reported that the sand and clay fraction were significantly ($P < 0.01$) affected by the interaction of land use. In general the majority of the soils in this present study were either sandy loam or clay loam indicating that the soils, due to their young nature, have not been highly weathered and are not pedologically mature (Yerima and Van Ranst, 2005).

The soils were generally acidic with pH in water ranging from 4.83 to 6.47 (Table 3).

Soils under mixed cropping with legumes had the highest pH values while those of mixed cropping without legumes had the lowest pH values. The presence of nitrogen fixing legumes could either increase or decrease soil pH depending on the initial acidity of the soil (reference). Calcium and magnesium dominated the exchange complex (Figure 2), with mean values of 8.3 cmol kg^{-1} and 2.5 cmol kg^{-1}, respectively. This observation is in line with the work of Nnaji et al. (2002) who also observed high amounts of calcium in soils under selected land utilization types. Braver et al. (1978) stated that calcium acts as a link between clay particles and organic polymers, which increases aggregate stability of soils. Exchangeable sodium was very low, reflecting the intact nature of the structure of these soils. High concentrations of sodium disperse soil colloids, disintegrating adsorption sites making nutrients not available to plants (Foth, 1984). The aluminium content of soils in this area was almost unavailable. This could be attributed to the fact that these soils are still young volcanic soils, which have not been highly weathered (Manga et al., 2013) unlike highly weathered acidic soils that contain significant amount of aluminium (Yerima and Van Ranst, 2005; Ngane et al., 2012).

The ranges for available phosphorus (P) were 3.58-24.15 mg kg^{-1}, 0.66-4.12 mg kg^{-1}, 0.02-52.22 mg kg^{-1}, 0.25-22.89 mg kg^{-1} for soils under mixed cropping without legumes, fallow land, mixed cropping with legumes and sole cropping, respectively. The concentrations of available P in the soil samples were generally low. This could be related to the high clay content and/or mineralogy of phyllosilicate minerals. Yerima and Van Ranst (2005), and Tening et al. (2012) reported a strong phosphate fixation in the soils of mount Cameroon. The high values of P recorded for some of the soils could be attributed to high applications of phosphate fertilizers in order to increase crop yield. Similarly, a high concentration of calcium was recorded in soils that had high values of P. Anions such as phosphates act as carriers for cations thus less leaching of phosphates means less cations will leach and vice versa (Galloway et al., 1983).

Total N and OC ranged from 0.18% to 0.81 % in soils under mixed cropping without legumes and from 1.50 % to 6.55% in soils under fallow land (Table 3). An insignificant ($p > 0.05$) relationship was observed within the land-use systems and OC, and total N (Table 4). One will expect an organic carbon build up in fallow but this was not significant probably due to the length of the fallow. However, quantitatively, the OC content was higher under fallow systems.

Soils under mixed cropping also showed high insignificant concentrations of organic matter compared to soils under sole cropping and mixed cropping without legumes. The high concentrations could be as a result of appropriate soil amendments (Sarvade et al., 2016b; Widowati et al., 2020; Zhao et al., 2021) and the crop cover created by the mixture of plants grown on these soils. Leguminous plants such as beans and groundnuts, which were frequently identified under the mixed cropping system, are able to enrich the soil in which they grow by their unique ability to fix atmospheric N. The variations of OC and total N could be as a result of soil tillage, burning, clearing of grass and continuous cultivation, which were the common practices in the study area. Ndukwu et al. (2010) and Gonzalez-Perez (2021) reported that clearing and burning, in a long run reduces inputs of organic material from vegetation and increase the rate of decomposition. As a result, the natural fertility of the soil is reduced through decreased availability of nutrients (Lal, 2003). Soils that are continuously being cultivated expose organic matter to rapid decomposition (Sanchez, 2002). .

Carbon-nitrogen (C/N) ratio of the soils had a mean value of 9.65, 9.16, 8.82, and 8.82 for sole cropping, mixed cropping, and mixed cropping without legumes and fallow land, respectively. These values are less than 15 implying that the rate of mineralisation of nitrogen exceeds that of immobilisation (Asongwe et al., 2016). The moisture content (MC) of the soils ranged from 25% in sole cropping to 45% in mixed cropping. Soils in Ekona had relatively higher values of MC, ECEC and OC indicating that these soils probably had relatively better chances of providing nutrients to plants since these parameters are indicators of a good soil structure, which will enhance root penetration.

Moisture content had a positive significant ($p<0.05$) correlation with ECEC ECEC ($r=0.972$) and MC ($r=0.982$) (Table 5), indicating that water is very crucial for the availability of micro and macro-nutrients to plant. Soil pH had a significant ($p<0.05$) positive relationship with calcium ($r=0.988$). There was also a highly significant positively correlation ($p<0.01$) between calcium and ECEC ($r=0.996$). This signifies that calcium increases the pH and ECEC of the soil and enhances the latter’s coagulating ability. Clay had a negative relationship with OC ($r=-0.733$), which was not significant at the 5% probability level. This could be due to the fact that the organic matter in association with clay is made up of mainly fulvic acids, which are very soluble, and form loosely bound compounds. It is mostly present in a liquid form unlike humic acid that is available in a semi solid form (colloid) with clay (Le Mare, 1991).

There was a significant ($p<0.05$) difference in clay and sand along an altitudinal gradient (Table 6). Soils from the highest altitudinal range (880-938 m a.s.l) had the highest sand fraction (71.39 %) and the lowest clay fraction (7.11 %). This is not unusual as the heavy rainfall in the Buea zone (windward side of the mountain) could be contributing to the washing away of the fine particles of the soil into lower altitudes.

Ekona zone had better soil quality variables compared to the Buea zone probably due to the fact that most of the pyroclastic minerals, ashes and mudflow materials have been washed down into the Ekona zone (Yerima and Van Ranst, 2005). The leeward side of the mountain, where Ekona zone is found, is less concave with fewer disturbances compared to Buea zone that is situated in the windward side of the mountain and experiences slight leaching of plant essential nutrients, water and wind erosion (Yerima and Van Ranst, 2005). The better quality of the Ekona zone soils may not be unconnected to the fact that the Ekona zone that is located at the foot of a younger lava flow is still undergoing weathering thereby releasing more nutrients to the soils of that zone. The Ekona zone could be harnessed for extensive agricultural activities.

For sustained crop production therefore, lesser inputs will be required in the Ekona zone than the Buea zone. This scenario was also observed by Uzoho et al. (2007). It has been estimated that 75% of soil fertility decline and 85% of water logging are due to agricultural activities (Weldemariam et al., 2020) Ezeaku and Davidson, 2008). It is worth mentioning some of these traditional soil conservation practices have been encouraged in the mount Cameroon region so as to control soil erosion. It has been shown that the traditional method of soil conservation has led to sustainable food production (Tekwa and Belel, 2009, De la Cruz-Amo et al, 2020).

3.2 Farmers' participation in the different land-use systems

Almost 46.0% of the farmers practiced mixed cropping without legumes. While 34.0% and 11.0% practiced mixed cropping with legumes and sole cropping, respectively, 9.0% practiced the fallow system (Table 7). These findings are not uncommon, as many of the farmers did not have ownership over the land they cultivated and the tendency of maximizing outputs from such lands was evident as they did not exactly know when it would be reclaimed. This fact was also supported by (Ritu, 2001). There is therefore need for these famers to be encouraged through the different mass media. Irfan et al. (2006) observed that the television was ranked first in disseminating agricultural technologies among farmers.

Crops that were commonly grown in this area included cassava (*Manihot esculentus*), maize (*Zea mays*), beans (*Phaseolus sp*), groundnuts (*Arachis hypogeal*), sweet potatoes (*Ipomoea sp*), okra (*Abelmosehus esculentus*) and tomatoes (*Lycopersicon esculentus*).

Conclusion

Soils under mixed cropping with legumes and the fallow system possessed better agronomic and soil quality indicators compared to those of sole cropping and mixed cropping without legumes. Sand and clay fractions of the soils varied with altitude indicating that altitude is also responsible for changes in soil properties especially particle size distribution. Ekona zone portrayed better soil quality compared to the Buea zone as the soils were not as weathered as those of Buea zone. Management practices should take into account all cultural practices which enrich soils for sustainable crop production and soil maintenance.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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Table 1. Sampling sites, location and land-use systems within the study area.

Sample No.	Sampling site	Location	Altitude (m.a.s.l)	Land-use systems
1	Bokwango	04 09.323N 009 14.425E	880	Mixed cropping-N*
2	Bokwango	04 07.801N 009 13.250E	938	Fallow land
3	Clerks Quarters	04 07.827N 009 13.268E	919	Mixed cropping-L*
4	Clerks Quarters	04 09.293N 009 14.405E	882	Sole cropping
5	Molyko	04 08.551N 009 17.222E	580	Mixed cropping-N
6	Molyko	04 08.538N 009	575	Fallow land

		17.225E		
7	Bunduma	04 09.695N 009 15.583E	770	Mixed cropping-L
8	Bokwai	04 09.844N 009 15.572E	784	Sole cropping
9	Mile 16	04 10.123N 009 18.314E	542	Mixed cropping-N
10	Mile 16	04 08.619N 009 18.430E	490	Fallow land
11	Mile 17	04 08.565N 009 18.360E	510	Mixed cropping-L
12	Muea	04 08.750N 009 18.264E	507	Sole cropping
13	Ekona	04 13.572N 009 19.449E	412	Mixed cropping-N
14	Ekona	04 13.955N 009 19.653E	402	Fallow land
15	Ekona	04 13.821N 009 19.709E	398	Mixed cropping-L

16	Ekona	04 13.818N 009 19.709E	400	Sole cropping

*N= without legumes; L = with legumes

Table 2: Particle size distribution and colour of soils in the eastern flank of mount Cameroon

Sample No.	Altitude/land-use systems*	Soil colour	Sand	Silt	Clay	Textural class
				%		
1	A1MN	7.5YR 4/4	59.71	30.11	10.18	Sandy loam
2	A1F	7.5YR 4/6	51.75	21.50	26.75	Sandy clay loam
3	A1ML	10YR 3/3	53.82	19.28	26.90	Sandy clay loam
4	A1S	7.5YR 4/4	71.39	21.50	7.11	Sandy loam
5	A2MN	5YR 3/3	37.78	25.97	36.25	Clayey loam
6	A2F	10YR 2/2	33.17	26.08	40.75	Clayey loam
7	A2ML	7.5YR 2.5/3	23.61	21.57	54.82	Clayey
8	A2S	5YR 4/3	31.46	25.02	43.51	Clayey
9	A3MN	5YR 3/3	22.33	27.35	50.32	Clayey
10	A3F	7.5YR 2.5/3	37.68	23.57	38.75	Clayey loam
11	A3ML	7.5YR 3/2	43.75	25.35	30.90	Clayey loam
12	A3S	10YR 4/4	31.75	25.21	43.04	Clayey
13	A4MN	7.5YR 4/2	29.82	27.57	42.61	Clayey loam
14	A4F	7.5YR 3/1	59.75	27.35	12.90	Sandy loam
15	A4ML	7.5YR 2.5/3	59.82	25.21	14.97	Sandy loam
16	A4S	10YR 3/3	54.46	26.90	18.64	Sandy loam

*A1= 880-938 m. a.s.l; A2 = 580-784 m. a.s.l; A3 = 490-542 m. a.s.l; A4 = 398-412 m. a.s.l;

MN = Mixed cropping without legumes; F = Fallow land; ML = Mixed cropping with legumes; S = Sole cropping.

Table 3. Physicochemical properties of soils in the eastern flank of mount Cameroon.

Sample No.	Altitude/ land-use systems*	pH (H_2O)	OC	Tot. N	C/N	Avail. P	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	ECEC	MC
			%			(mg kg^{-1})	cmol$_c$ kg^{-1}						(%)
1	A1 MN	5.27	3.21	0.32	10.12	3.58	3.68	0.61	0.28	0.05	0.01	4.62	28.00
2	A1 F	5.38	3.82	0.41	9.42	2.42	6.20	2.61	0.43	0.05	0.01	9.29	35.00
3	A1 ML	5.24	3.72	0.41	9.06	3.99	5.59	2.40	0.54	0.06	0.01	8.60	36.00
4	A1 S	5.79	3.46	0.31	11.31	22.89	7.78	1.42	0.80	0.08	0.01	10.09	25.00
5	A2 MN	6.08	2.84	0.35	8.20	24.15	13.38	3.07	1.76	0.05	0.01	18.26	30.00
6	A2 F	5.48	2.62	0.32	8.07	4.12	9.87	2.98	0.54	0.05	0.01	13.45	29.00
7	A2 ML	5.96	1.58	0.29	8.73	0.02	6.08	1.63	0.29	0.09	0.01	8.09	45.00
8	A2 S	4.83	2.45	0.28	8.61	0.25	3.74	1.42	0.18	0.04	0.01	5.39	30.00
9	A3 MN	5.06	1.50	0.18	8.16	14.60	4.26	1.05	0.54	0.03	0.01	5.89	28.00
10	A3 F	5.26	2.02	0.24	8.50	0.66	5.83	3.32	0.27	0.05	0.01	9.48	28.00
11	A3 ML	6.47	2.98	0.32	9.38	52.22	19.55	3.83	1.64	0.04	0.01	25.07	26.00

12	A3 S	5.12	2.12	0.23	9.13	14.82	5.88	2.68	0.80	0.06	0.01	9.43	27.00
13	A4 MN	5.09	2.46	0.28	8.79	5.35	6.97	2.56	0.55	0.03	0.01	10.12	30.00
14	A4 F	6.00	6.55	0.81	8.14	0.73	12.72	3.20	0.24	0.07	0.01	16.24	36.00
15	A4 ML	5.98	5.91	0.62	9.47	0.39	10.96	3.68	0.41	0.06	0.01	15.12	41.00
16	A4 S	5.65	6.05	0.61	9.90	0.66	11.02	3.82	0.46	0.06	0.01	15.37	39.00

*A1= 880-938 m. a.s.l; A2 = 580-784 m. a.s.l; A3 = 490-542 m. a.s.l; A4 = 398-412 m. a.s.l; MN = Mixed cropping without legumes; F = Fallow land; ML = Mixed cropping with legumes; S = Sole cropping.

Table 4. Relationship between soil properties and the land-use systems.

Land-use systems	Sand	Clay	OC	Tot. N	ECEC	Avail. P
	%				(cmol kg^{-1})	(mg kg^{-1})
Mixed cropping-N[#]	37.41^{a*}	34.84^{a}	2.50^{a}	0.28^{a}	9.72^{a}	11.92^{b}
Fallow land	45.59^{a}	29.79^{a}	3.75^{a}	0.44^{a}	12.12^{a}	1.98^{a}
Mixed cropping-L[#]	45.25^{a}	31.90^{a}	3.54^{a}	0.38^{a}	14.22^{b}	14.15^{c}
Sole cropping	47.27^{a}	28.08^{ab}	3.52^{a}	0.36^{a}	10.07^{a}	9.65^{b}

[#] N = without legumes; L = with legumes

* Values represent means of four replicates. Values in the same column followed by different letters differ significantly at $p< 0.05$ according to Fisher's protected LSD.

Table 5. Pearson correlation coefficient (r) of some physicochemical properties of soils from the study area.

	Sand	Silt	Clay	pH	Ca^{2+}	Mg^{2+}	ECEC	Tot. N	Avail. P	OC
Silt	0.037	-								
Clay	-0.834	0.582	-							
pH	0.264	0.642	0.569	-						
Ca^{2+}	0.350	0.530	0.779	0.988*	-					
Mg^{2+}	0.888	0.484	0.910	0.659	0.764	-				
ECEC	0.418	0.474	0.602	0.972*	0.996**	0.551	-			
Tot. N	-0.781	0.295	0.474	0.390	0.523	0.672	0.596	-		
Avail. P	-0.310	0.908	0.249	0.325	0.180	0.043	0.105	-0.668	-	
OC	0.946	0.067	0.733	0.408	0.518	0.887	0.588	0.936	0.461	-
MC	0.438	0.639	0.710	0.982*	0.982*	0.623	0.977*	0.486	0.282	0.549

*Significant at the 0.05 level.

**Significant at the 0.01 level.

Table 6. Relationship between some soil properties and altitude.

Altitude	Sand	Clay	OC	Tot. N	ECEC	Avail. P
(m)	%				(cmol kg^{-1})	(mg kg^{-1})
880-938	59.17^{b*}	17.74^{a}	3.55^{a}	0.36^{a}	8.15^{a}	8.22^{a}
575-770	31.51^{a}	43.83^{b}	2.37^{a}	0.28^{a}	11.3^{a}	7.13^{a}
490-542	33.88^{a}	40.75^{b}	2.15^{a}	0.24^{a}	12.47^{a}	20.57^{b}
398-412	50.96^{b}	22.28^{a}	5.24^{a}	0.58^{a}	14.21^{a}	1.78^{a}

* Values represent means of four replicates. Values in the same column followed by different letters differ significantly at $p < 0.05$ according to Fisher's protected LSD

Table 7. Farming operations in the study area.

Land-use systems	Respondent (%)	Farming activity	Dominant crop	
			Common name	Scientific name

Mixed cropping-N* (≥ 5 years old)	46.0	Clearing and burning, soil tilling, fertilizers, pesticides and herbicides	Cassava Sweet potatoes Maize	*Manihot esculentus* *Ipomoea sp* *Zea mays*
Fallow land (≤ 5 years old)	9.0	Non	Elephant grass	*Pennistum sp*
Mixed cropping-L* (≥5 years old)	34.0	Raking, clearing, tilling, insecticide and fertilizer application	Beans Groundnut Maize Okra	*Phaseolus sp* *Arachis hypogeal* *Zea mays* *Abelmosehus esculentus*
Sole cropping (≥ 5years old)	11.0	Weeding, raking, tilling, clearing and burning, digging, external outputs	Tomatoes only	*Lycopersicon esculentus*

*N = without legumes; L = with Legumes

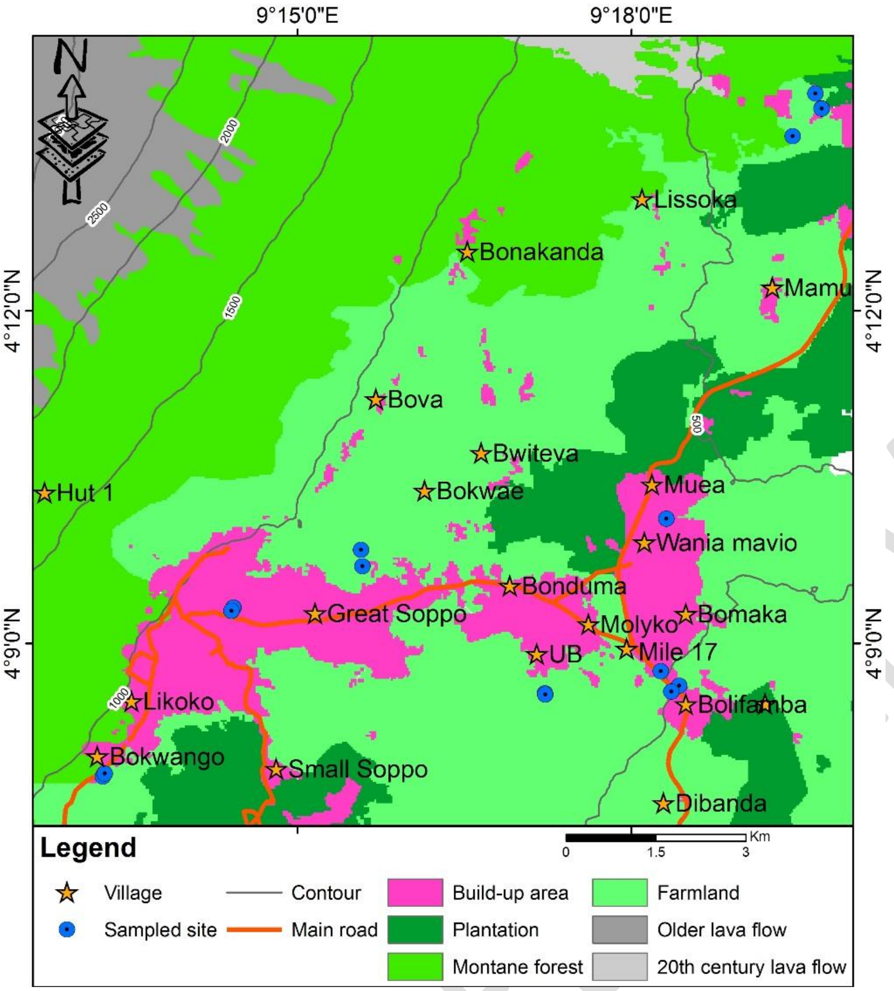
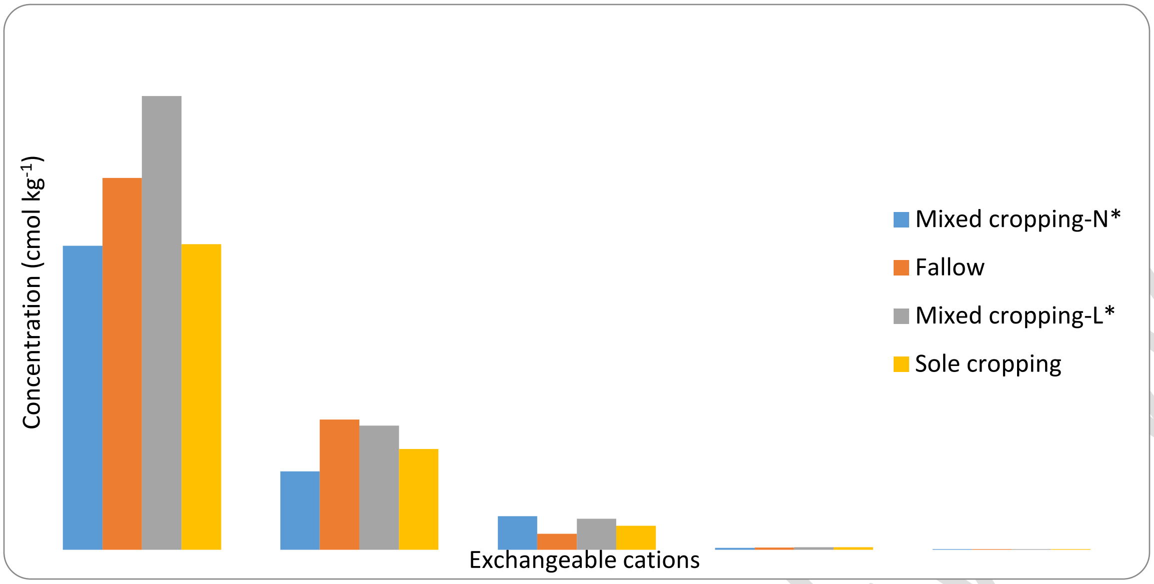
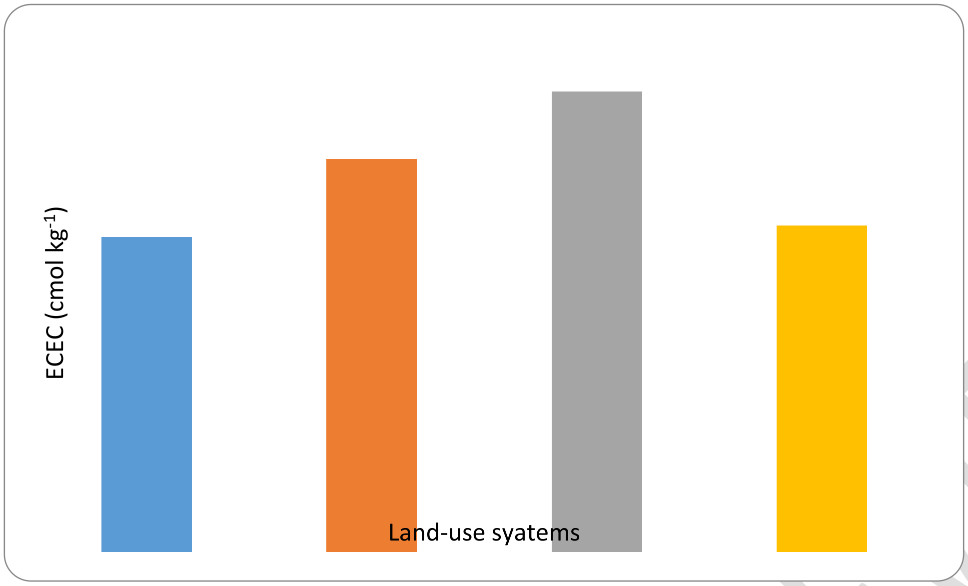


Figure 1. Map of study area showing the different sampling sites



*N = without legumes; L= with legumes

Figure 2. Concentrations of exchangeable cations in the soils from the different land-use systems (Averaged over altitudes).



*N = without legumes; L= with legumes

Figure 3. The ECEC of soils from the different land-use systems (Averaged over altitudes).