International Scholars Journals

African Journal of Soil Science ISSN 2375-088X Vol. 11 (9), pp. 001-013, September, 2024. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Assessment of Soil Physico-Chemical Properties and Land Suitability for Maize (Zea mays), Beans (*Phaseolus vulgaris*), and Irish Potatoes (*Solanum tuberosum*) in the Tephra Soils of Mount Kupe's Western Slopes, Cameroon

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Received 5 May, 2024; Accepted 5 August, 2024

Soils of the western slopes of Kupe Mountain in Cameroon were characterized to understand their proper land use and sustainable management. Evaluation of land suitability for maize (*Zea mays*), beans (*Phaseolus vulgaris*) and Irish potatoes (*Solanum tuberosum*) were assessed, considering the socio-economic importance of these crops in Cameroon. Three sites, representative of the study area were identified following a toposequence; Nyassosso (900 m), Mbule (700 m) and Tombel (500 m) with soils, respectively, classified as: Hyperdystri – humic Leptosol (loami – andic), Skeleti – Umbric Andosol (colluvi – loamic) and Dystri – skeletic Andosol (Colluvi – loamic). Soil properties indicated that colour varies from black and brownish black at the surface to reddish brown in subsurface horizons with some horizons showing varied colours. The soils were friable and granular in structure, had low bulk density ranging from 0.38 to 1.08 g/cm^3, and had a loamy texture. Chemically, $pH_{(H2O)}$ ranged from strongly acidic to slightly acidic (4.8 - 6.2), organic carbon ranged from low to very high (0.88 - 7.26%), electrical conductivity was very low (0.02 - 0.29 dS/m), cation exchange capacity ranged from medium to high (20.5 to 38.08 $cmol(+)kg^{-1}$), total nitrogen from very low to very high (0.09 - 1.7%), available phosphorous from very low to low (7.13 - 19.76 ppm), Ca^{2+} from very low to high (2.08 - 10.64 $cmol(+)kg^{-1}$), Mg^{2+} from very low to medium (0.08 to 2.56 $cmol(+)kg^{-1}$), K^+ from very low to medium (0.01 0.31 $cmol(+)kg^{-1}$) and Na^+ was very low (0.01 - 0.05 $cmol(+)kg^{-1}$). Amorphous iron and aluminum ranged between 0.06 - 1.35 and 0.16 - 1.01%, respectively. Land suitability evaluation indicated that soils of Nyassosso were marginally suitable for rain-fed cultivation of Irish potatoes, beans and maize. Soils of Mbule were marginally suitable for rain-fed cultivation of Irish potatoes and maize but not suitable for beans, while soils of Tombel were marginally suitable for rain-fed cultivation of Irish potatoes and temporarily non suitable for rain-fed cultivation of maize and beans.

Key words: Mount Kupe, soil properties, suitability classes, climatic index, land index.

INTRODUCTION

Food security is at the top of the list of Millennium Development Goals (MDGs) with the goal of eradicating poverty and hunger, especially in sub-Saharan Africa where the situation remains a great challenge due to rapid population growth (Bremner, 2012). In Cameroon and most sub-Saharan African countries, per capital food production continues to decline due to insufficient food production (Sanchez, 2005). Optimal food production is further constrained by the serious degraded nature of most African soils (Nkonya et al., 2016). Volcanic tephra soils are among the most productive soils in the world since they accumulate large amounts of organic carbon (OC) and nitrogen (N) (Shoji and Takahashi, 2002). In the Mount Kupe area of Cameroon, these soils have been extensively used for cultivation of African oil palm (*Elaeis guineensis*), cocoa (*Theobroma cacao*), tubers such as cassava (*Manihot esculenta*) and taro (*Colocasia esculenta)*, and plantains (*Musa* spp.) and banana (*Musa* spp.). In order to meet the high demand for food in this locality due to increase in population, and to improve on the local nutritional standards and promote crop diversification, there is a need to evaluate the suitability of these soils for other crops. Furthermore, because of the pressures that an increasing population and economic growth have put on limited land resources, land suitability evaluation is recommended since it can assist in the efficient use of land resources at a regional level (Gong et al., 2012). Land evaluation, using a scientific procedure is essential to identify the potential and constraints of a given land for defined use (agriculture for our case) in terms of its fitness and ensure its sustainable use (Nahusenay and Kibebew, 2015). The objective of this study was to qualitatively assess the physical and chemical land suitability for rain-fed cultivation of maize (*Zea mays*), beans (*Phaseolus vulgaris*) and Irish potato (*Solanum tuberosum*), given their importance at the local and national scale. Furthermore, there is great necessity for understanding of soils of this area through proper characterization in order to propose management strategies that will make the farming systems of the area sustainable. Crop yield is generally dependent on the fertility status of the soil, and this soil quality combines several soil properties (physical, chemical and biological), all of which affect directly or indirectly nutrient dynamics and availability (Akinrinde, 2004; FAO, 2006a). These soil properties alongside environmental or climatic conditions are the determinants of sustainable crop production through proper soil fertility management, and for the special case of farmers, the most important properties of soils are their physical condition and chemical fertility (FAO, 2006a).

Evaluation of land suitability for the production of maize, beans and Irish potatoes has been done in the western highlands of Cameroon, notably around mount Bambouto, where the climate is colder (Tsozué et al., 2015) and soils vary among, oxisols, inceptisols, entisols and andosols (Tematio et al., 2004). Mount Kupe is one of the few areas in Africa where virgin forests exist. Humidity at mount Kupe and the surrounding areas isvery high, usually above 80%. The need for land suitability evaluation of these three crops: maize, beans and Irish potatoes comes from the fact that these crops are highly consumed in Cameroon and their demand keeps increasing with the increasing population.

MATERIALS AND METHODS

Study area

Mount Kupe is located at latitude 4°48' N and longitude 9°42' E, approximately 100 km North of Mount Cameroon (Figure 1). It has a very heterogeneous terrain with steep slopes, long shrunken ridges, rocky outcrops, bare cliffs and small peaks. It also has flat contrasting areas between the peaks at an altitude of 1,600 m. It was formed as a result of geological fractures and is 2,064 m high, limited by structural depressions (Gartlan, 1989). Volcanic activity occurred in these depressions and several cones are visible on the lower flanks of the mountain.

The soils of Mount Kupe are young and relatively fertile. The mid-slopes and lower slopes have deep and fertile soils (Gartlan, 1989). Micro-aggregated cambisols are more common and more developed than entisols. There is no evidence of peat formation at high altitudes and the soils are usually well drained.

The climate is the mountain Cameroon type, typical of central Africa precisely with two seasons: the rainy season from March to October accounting for about 80% of annual precipitation (the wettest months are from July to September accounting for 50% of the precipitation) and the dry season for the rest of the year.

The drainage system consists of several permanent streams emanating from mount Kupe which acts as a watershed for collecting and supplying the surrounding villages with water (Gartlan, 1989).

Soil description and sampling

Three sites, representative of the study area were identified following a toposequence: Nyassosso (at an altitude of 900 m at the foot of mount Kupe, located at Lat. 4° 49' 32.8" N, Long. 9° 41' 9.1" E), Mbule (at an altitude of 705 m, located at Lat. 4° 48' 0.7" N, Long. 9° 39' 45.4" E) and Tombel (at an altitude of about 475 m, located at Lat. 4° 43' 31.3" N, Long. 9° 41' 20.5" E). At each of the sampling sites, a representative soil profile in virgin land was dug. The profiles were described following the FAO guidelines (FAO, 2006b). Soil samples were collected per horizon, stored in

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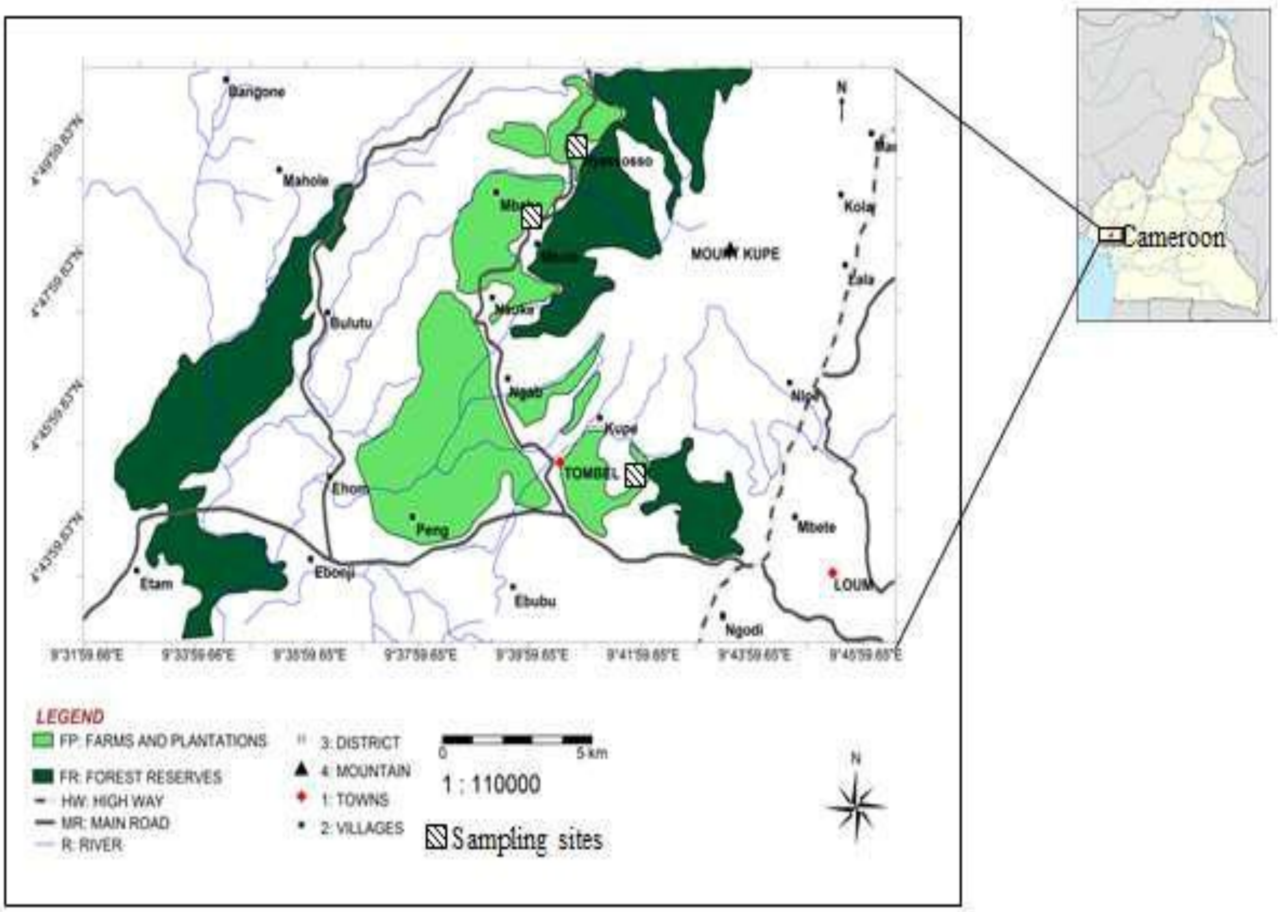

Figure 1. Location of Mount Kupe, the surrounding areas and sampling sites, at Cameroon.

polythene bags, and characterized for classification of the soils. Undisturbed samples for bulk density were collected in duplicates for quality control using Kopecky rings of 100 cm^3 volume. At each site, 16 representative surface samples were randomly collected at a depth of 0 to 30 cm, homogenized and characterized for evaluation of land suitability. A general description and soil classification of the sites harboring the three profiles studied are summarized in Table 1.

Laboratory analyses

Chemical properties were determined following procedures described by Pauwels et al. (1992). Soil OC content was determined by the Walkley and Black wet combustion method, while bulk density was determined as the oven dry (105°C) mass of each undisturbed core sample per volume. A 1:2 soil-H_2O and 1:2 soil-KCl solutions were used for $pH_{(H2O)}$ and $pH_{(KCl)}$ determinations, respectively. Total N and available phosphorous (P) were determined by the Kjeldahl wet digestion and the Bray II methods, respectively. Exchangeable bases were determined following the Schollenberger method using a 1 M ammonium acetate solution buffered at pH 7. The concentrations of exchangeable sodium (Na^+) and potassium (K^+) in the extract were obtained by flame photometry, and for calcium (Ca^{2+}) and magnesium (Mg^{2+}) by complexometry using a 0.002 M Na_2-EDTA solution. Cation exchange capacity (CEC) was determined by a direct continuation of the Schollenberger's method using a 1 N KCl solution for displacement of ammonium ions. Exchangeable acidity (Al^{3+} + H^+) was determined after displacement with a 1 N unbuffered KCl solution. Amorphous iron (Fe) and aluminum (Al) were determined by acid ammonium oxalate extraction (Pauwels et al., 1992). The hydrometer method was used for particle size distribution following procedures described by Bouyoucos (1962) after dispersion of the soil with a 2.5 N sodium hexametaphosphate solution to ensure proper dispersion of the soils.

Determination of the growing period in the study area

After obtaining the daily precipitation for 31 years, the average monthly precipitation over a 31-year period was determined. The potential evapotranspiration (PET) (Figure 2) was estimated using the radiation method (Jensen et al., 1990) defined as follows:

where: c is a coefficient depending on the relative humidity and wind speed, representing an adjustment factor as presented in the Penman (1948) equation; W represents a weighting for the effect of radiation on PET at a particular temperature and altitude. Rs is the total solar radiation, a function of sunshine hours and extra-

Table 1. Description of study sites and soil classification of representative soil profiles.

Site characteristics	Nyassosso series	Mbule series	Tombel series
Land use/vegetation	Protected forest, apparently early exploitation of timber. Marantaceae, shrubs, *Carapa grandiflora*, *Cephaelis mannii*, *Dictonalepsis vestita*, *Ficus mucuso*, *Garcinia smaethmannii*, *Dorstenia*, *Dracaena*, *Haemanthus* and *Selaginella*.	Natural evergreen forest Marantaceae vegetation, twigs/twines, *Garcinia smaethmannii*, *Dorstenia*, *Dracaena*.	Evergreen forest, apparently early exploitation of timber. Marantaceae vegetation, twigs/twines, *Garcinia smaethmannii*, *Dorstenia*, *Dracaena*.
Physiography	Foot slope, 2 - 5 % (gently sloping), and presence of many pyroclastic rock out-crops (15 – 40 %) about 5 – 20 m apart, mountainous, occurrence of many streams signaling fault and fracture lines. Good internal and external drainage. Signs of slight geologic erosion.	Strongly sloping landscape. Middle slope, 10-15 %, absence of rock outcrops, unstable landscape susceptible to landslides. Very good internal and external drainage. Signs of geologic erosion.	Sloping landscape, (5-10 %), Sub mountain evergreen forest, few rock outcrops, pumice and scoria, all of quaternary origin. Good internal and external drainage, geologic erosion.
Relief/elevation	Highland 900 m	Highland 705 m	Graben 475 m
Parent material	Volcanic tephra (coarse tuff and scoria)	Volcanic tephra deposits (pumice, coarse tuff, scoria)	Volcanic tephra (pumice, scoria, coarse tuff)
Soil classification	Hyperdystri – humic Leptosol (loami – andic)	Skeleti – Umbric Andosol (colluvi – loamic)	Dystri – skeletic Andosol (Colluvi – loamic)
Soil temperature regime	Hyperthermic	Hyperthermic	Hyperthermic
Soil moisture regime	Udic	Udic	Udic

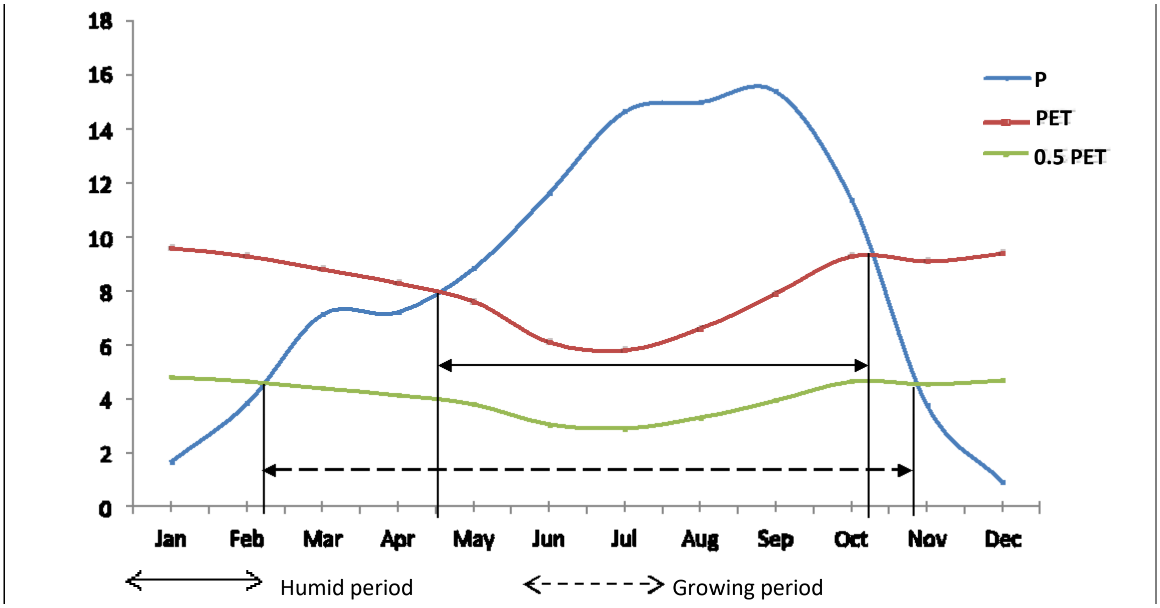

Figure 2. Climatic diagram of the study area showing the growing period. P = precipitation, PET = potential evapotranspiration.

Table 2. Qualitative land suitability classes for the different land indices.

Land index	Definition	Symbol
90-100	Highly suitable with no limitations	S1- 0
85-90	Highly suitable with slight limitations	S1- 0/1
75-85	Highly suitable with slight limitations	S1-1
60-75	Highly suitable to moderately suitable	S1-1/S2
50-60	Moderately suitable	S2
40-50	Moderately suitable to marginally suitable	S2/S3
25-40	Marginally suitable	S3
15-25	Marginally suitable to not suitable	S3/N
0-15	Not suitable	N

Adapted from Beernaert and Bitondo (1993).

Table 3. Classification of critical fertility levels in soils for organic carbon (OC), total nitrogen (N), available phosphorous (P), cation exchange capacity (CEC), base saturation (BS) exchangeable cations and soil reaction.

Soil properties	Critical fertility level				
(< 2 mm fraction)	**Very low**	**Low**	**Medium**	**High**	**Very high**
OC (%)	< 0.4	0.4-1.0	1.0-1.8	1.8-3.0	> 3.0
Total N (%)	< 0.05	0.05 - 0.125	0.125 - 0.225	0.225 - 0.30	> 0.30
C/N	< 10 = good, 10 - 14 = medium and > 14 = poor				
Ca^{2+} (cmol$_c$kg^{-1})	< 2	2 - 5	5-10	10-20	> 20
Mg^{2+} (cmol$_c$kg^{-1})	< 0.5	0.5 - 1.5	1.5 - 3.0	3 - 8	> 8
K^{+}(cmol$_c$kg^{-1})	< 0.1	0.1 - 0.3	0.3 - 0.6	0.6 -1.2	> 1.2
Na^{+} (cmol$_c$kg^{-1})	< 0.1	0.1 - 0.3	0.3 - 0.7	0.7 - 2.0	> 2.0
P (mgkg^{-1})	< 7	7-16	16 - 46	> 46	-
pH$_{(H2O)}$	≤5.5 (strongly acidic)	5.6 - 6.0 (moderately acidic)	6.1 - 6.5 (slightly acidic)	7.4 - 7.8 (slightly alkaline)	7.9 - 8.4 (soderately alkaline)
CEC (cmol(+)kg^{-1})	< 6	6-12	12 - 25	25 - 40	> 40
BS (%)	0-20	21 - 40	41 - 60	61 - 80	81 - 100
EC (dS/m)	< 2 (non - saline)	2 - 4 (slightly saline)	4 - 8 (moderately saline)	8-16 (highly saline)	> 16 (extremely saline)

Adapted from Cass (1998), Hazelton and Murphy (2007), and Euroconsult (1989).

terrestrial radiation.

Land use, crop requirements and evaluation of land suitability

The land use envisaged is rain fed cultivation of maize, beans and Irish potatoes by small scale farmers at minimal management level. Land suitability assessment was done using tables for different crop requirements in land evaluation proposed by Sys et al. (1993). The evaluation method enabled the identification of both soil and climatic parameters limiting the growth and production of the selected crops in the study area. A parametric method was used to classify the suitability of the soils as highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). In this parametric method, land and climatic characteristics are defined using different ratings. These characteristics were determined using the Storie method (a parametric method) as described by Sys et al. (1993).

where, I is the specified index and A, B, C, D, E, etc, are different ratings given for each property.

Climatic characteristics considered in this study were rainfall, temperature and relative humidity, while land characteristics considered were topography (slope), wetness (flooding and drainage), soil physical characteristics (texture, coarse fragment volume % and soil depth), soil fertility characteristics (CEC, base saturation- BS, OC, soil reaction - pH), salinity (electrical conductivity - EC) and alkalinity (exchangeable sodium percentage- ESP).

By determining the land index and making use of guidelines outlined by Sys et al. (1991), the qualitative land suitability classes (Table 2) and the limiting factors for plant growth in different soil series for each crop were determined. Critical values of soil nutrients and soil fertility parameters are shown in Table 3.

RESULTS AND DISCUSSION

Morphological properties

Soil colour

In profile 1, colour varies from dark reddish brown (5YR 3/3) in the A horizon to dull reddish brown (5 YR 5/4, 5 YR 4/4, 5 YR 4/4) in the ABw, Bw and Bw/Cr horizons, respectively. Colour in profile 2 is brownish black (5YR 2/2) in the A horizon, dark reddish brown (5YR 3/2) in the Bw horizon, brownish black (7.5 YR 3/2) in the 1C horizon, dark brown (7.5 YR 3/3) in the 2C and 3C horizons, a brownish black (5YR 2/1) matrix with very dark reddish brown (2.5YR 2/3) inclusions in the 4C horizon and very dark reddish brown (7.5 YR 2/3) in the 5C horizon (Table 4).

Profile 3 colour varies from brownish black (5 YR 3/1) in the A horizon, through dark reddish brown (5 YR 3/3) in the Bw/Cr horizon to Black (5 YR 1.7/1) in the Cr horizon. The presence of different colours in this profile reflects the varied parent materials observed (Brady, 1990), dominated by tuff and scoria with some colluvial material mostly of granitic nature.

Soil structure, consistence and texture

All the three soil profiles have dominantly granular structure (Table 4) which reflects the parent materials from which these soils were developed. This structure has great influence on soil stability. Field observations indicated that landslides were very common in the study area due to the occurrence of K-cycles described by Fitz Patrick (Yerima and Van Ranst, 2005a). These soils are of low stability and are inappropriate for infrastructural works.

The surface horizons of these soils are friable when moist and slightly sticky to sticky and slightly plastic to plastic when wet, while in subsurface horizons it is firm when moist and dominantly non sticky and non-plastic when wet.

These morphological properties are consistent with the soil texture which is dominated by the sand fraction, followed by clay which gives the soils a loamy texture.

Physical properties

The three soils have bulk density values varying from 0.38 to 1.08 g/cm^3 with an average value of 0.71 g/cm^3 (Table 4). These values are typical of volcanic ash soils which generally have a bulk density less than 0.9 g/cm3 (Olafur, 2008). In profiles 1 and 2 (Nyassosso and Mbule series), variations of bulk density with depth are erratic. These profiles are located in areas with frequent deposition of colluvial materials associated with the unstable geomorphic surfaces, especially for profile 2 located on a strongly sloping landscape (Table 1). In profile 3 (Tombel series), bulk density has a regular depth function. Tombel is a graben with a greater stability as compared to the other two series.

Apparently the stability of the geomorphic surface would enable the development of a soil with a higher profile differentiation. Particle size analysis indicates that, the sand fraction is dominant in all the three soils, followed by the clay fraction. In all the three soils, sand content > clay content > silt content.

Chemical properties

Soil reaction (pH)

All three soils are acidic in nature (Table 5). pH$_{(H2O)}$ values range between 5.1 and 6.2, while pH$_{(KCl)}$ values ranged from 3.6 to 4.9 for profile samples. For surface samples, pH$_{(H2O)}$ values varied from 4.8 to 6.2, while pH$_{(KCl)}$ values range between 3.5 and 4.8. Therefore, the soils can be considered with moderate acidity, typical of mineral soils in humid regions (Brady, 1974). The acidity of these soils is associated with the high rainfall, coupled with the porous nature of the soils, resulting in the leaching of bases. For all the profiles, pH increases with depth, which is consistent with the leaching of bases.

Organic carbon

Organic carbon contents are relatively high in all soils (Table 5). Distribution of OC within profiles especially for profiles 1 and 2, are erratic. Alternation of organic matter with volcanic ash layers as indicated by bulk density values explains the erratic distribution of OC with depth. Colluvial deposits and landslides frequently observed at these sites are responsible for the occurrence of buried horizons which explain the high organic matter contents in subsurface horizons as compared to that of surface horizons.

The prevalence of earth movements at these sites apparently hinder a progressive evolution of soils in these environments, resulting in erratic distributions of soil properties with depth. Erratic OC depth functions have been reported in soils in similar environments (Kubotera and Yamada, 1995). The mineralization of the OC is retarded by the presence of allophane in these soils, which forms more stable allophane-humus complexes (Yerima and Van Ranst, 2005a). In profile 3 however, distribution of OC with depth follows a regular decreasing pattern with depth. These soils are located in a graben where the stability of the geomorphic surfaces enables a more progressive and regular development of soil.

Total nitrogen

Total nitrogen (TN) in these soils ranged from low

Table 4. Morphological and physical characteristics of representative soil profiles in the study area.

Horizon	Depth (cm)	Colour (moist)	Sructure	Consistence		Boundary	Porosity (%)	BD (g/cm^3)	Sand (%)	Silt (%)	Clay (%)	Coarse fraction > 2 mm (%)	Textural Class
				Moist	Wet								
Nyassosso series: Hyperdystri – humic Leptosol (loami – andic)													
Oi	0-10	-	-	-	-	-	-	-	-	-	-	-	-
A	10-20	5YR 3/3	FI, SB→GR	FR	SST and PL	C and S	75.1	0.66	77.3	5.8	16.9	17	SL
ABw	20-40	5YR 5/4	FI, SB→GR	FR	SST and SPL	C and S	69.8	0.8	78.6	4.3	17.1	19	SL
Bw	40-80/90	5YR 4/4	SB→GR	FR	SST and SPL	D and B	59.3	1.08	78.2	6.4	15.4	16	SL
Bw/Cr	80/90-115	5YR 4/4	SB	FR	NST and NPL	D and S	59.6	1.07	74.0	9.7	16.3	23	SL
Mbule series: Skeleti – Umbric Andosol (colluvi – loamic)													
Oi	0-5	-	-	-	-	-	-	-	-	-	-	-	-
A	5-20	5YR 2/2	FI GR	FR	SST and SPL	C and S	80.75	0.51	71.8	2.3	25.9	19	SCL
Bw	20-65	5YR 3/2	FI, CO GR	FR	SST and SPL	C and S	72.83	0.72	69.8	9.7	20.5	25	SCL
1C	65-78	7.5 YR 3/2	CO GR	FI	NST and NPL	A	77.74	0.59	74	5.3	20.7	31	SCL
2C	78-98	7.5 YR 3/3	CO GR	FR	NST and NPL	A	74.72	0.67	71.9	4.7	23.4	29	SCL
3C	98-140	7.5 YR 3/3	CO GR	FR	NST and NPL	A	76.23	0.63	69.5	11.9	18.6	42	SL
4C	140-155/140-165	5YR 2/1 (matrix), 2.5YR 2/3(inclusions)	CO GR	FR	SST and NPL	C and W	76.98	0.61	76.8	2	21.3	39	SCL
5C	155/165-200	7.5 YR 2/3	CO GR	FR	SST and NPL	C and W	75.85	0.64	76.7	6.7	16.7	44	SL
Tombel series: Dystri – skeletic Andosol (Colluvi – loamic)													
Oi	0-10	-	-	-	-	-	-	-	-	-	-	-	-
A	10-22	5 YR 3/1	FI GR	FR	NST and NPL	C and S	85.66	0.38	65.6	2.2	32.2	33	SCL
Bw/Cr	22-86	5 YR 3/3	CO GR	FI	NST and NPL	C and S	72.45	0.73	75.5	4.3	20.2	41	SCL
Cr	86-155	5YR1.7/1	SB	VFI	NST and NPL	D and I	67.17	0.87	81.9	6.5	11.6	59	LS

SB = Sub angular blocky, GR = Granular, SB→GR = Sub angular blocky parting to Granular, FI = Fine/thin (1-2 mm), ME = Medium (2-5 mm), CO = Coarse/thick (5-10 mm), WE = Weak, MS = Moderate to Strong, FR = Friable, FI = Firm, VFI = Very firm, ST = Sticky, SST = Slightly sticky, PL = Plastic, NST = Non-sticky, NPL = Non-plastic, C = Clear (2-5 cm), G = Gradual (5-15 cm), D = Diffuse (>15 cm), S = Smooth, W = Wavy, I = Irregular, A = Abrupt. NB: FI= fine (for structure) and firm (for consistence). Source: FAO (2006b).

Table 5. Chemical characteristics of the representative soil profiles in the study area.

Horizon/depth (cm)	pH H_2O	pH KCl	OC (%)	Total N (%)	C/N	P Bray II (mg kg^{-1})	Exch. bases (cmol(+)kg^{-1})				∑bases	Exch. Al^{3+}	CEC pH7 (cmol(+)kg^{-1})	BS (%)	ESP (%)	EC (mS/cm)	Ammonium oxalate extractable	
							K^+	Na^+	Mg^{2+}	Ca^{2+}							Al_2O_3	Fe_2O_3
Nyassosso series: Hyperdystri – humic Leptosol (loamy – andic)																		
Oi (0-10)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A (10-20)	5.1	4	4.44	0.67	6.63	9.41	0.21	0.03	0.72	2.32	3.28	0.6	26.24	13	0.11	0.2	0.26	0.67
ABw (20-40)	5.2	3.6	2.25	0.36	6.25	8.84	0.25	0.03	0.08	2	2.36	0.08	23.68	10	0.13	0.04	0.26	0.06
Bw (40-80/40-90)	5.5	3.7	2.73	0.23	11.87	11.12	0.02	0.01	0.16	2.24	2.43	0.52	23.04	11	0.04	0.02	0.19	0.89
Bw/Cr(80-115/90-115)	5.5	3.8	2.34	0.16	14.63	10.55	0.01	0.01	0.64	2.8	3.46	0.56	22.4	15	0.04	0.02	0.16	0.14
Mbule series: Skeleti – Umbric Andosol (colluvi – loamic)																		
Oi (0-5)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A (5-20)	5.2	4.2	5.38	0.91	5.91	11.12	0.05	0.02	0.56	9.44	10.07	0.1	30.72	33	0.07	0.29	0.97	0.44
Bw (20-65)	5.7	4.3	2.07	0.15	13.80	7.13	0.31	0.05	2.56	5.12	8.04	-	27.2	30	0.18	0.02	0.37	1.12
1C (65-78)	5.9	4.5	0.88	0.13	6.77	9.98	0.2	0.03	1.04	6.24	7.51	-	23.68	32	0.13	0.03	0.32	0.44
2C (78-98)	6.2	4.6	1.88	0.15	12.53	11.12	0.25	0.04	2.4	8.8	11.49	-	22.08	52	0.18	0.03	0.99	0.21
3C (98-140)	6.2	4.4	3.26	0.41	7.95	10.55	0.03	0.01	1.36	10.64	12.04	-	35.2	34	0.03	0.04	1.01	1.19
4C (140-155/140-165)	6.2	4.6	1.87	0.12	15.58	13.39	0.25	0.03	2.32	8.08	10.68	-	37.12	29	0.08	0.03	0.44	1.35
5C (155/165-200)	6.2	4.6	1.76	0.09	19.56	9.98	0.24	0.03	0.88	6.08	7.23	-	30.08	24	0.10	0.03	0.26	0.97
Tombel series: Dystri – skeletic Andosol (Colluvi – loamic)																		
Oi (0-10)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A (10-22)	5.6	4.7	7.26	1.70	4.27	15.47	0.02	0.01	1.52	6.24	7.79		38.08	20	0.03	0.12	0.41	0.89
Bw/Cr (22-86)	5.8	4.9	4.31	0.50	8.62	17.22	0.08	0.01	1.28	7.92	9.29		22.08	42	0.05	0.03	0.30	0.74
Cr (86-155)	5.9	4.9	2.33	0.21	11.10	19.76	0.12	0.04	1.33	7.98	9.47		20.5	46	0.20	0.02	0.32	0.82
Mean values of chemical properties for surface samples in the study area																		
Depth (cm)							**Nyassosso series: Hyperdystri – humic Leptosol (loamy – andic)**											
0–30	5.3	3.9	4.86	0.46	10.57	9.03	0.24	0.03	0.29	2.11	2.67	0.25	24.53	10.88	0.12	0.09	0.26	0.26
								Mbule series: Skeleti – Umbric Andosol (colluvi – loamic)										
0–30	5.7	4.4	4.67	0.34	13.74	8.13	0.25	0.04	2.06	6.20	8.55	-	28.08	30.45	0.14	0.09	0.52	0.95
								Tombel series: Dystri – skeletic Andosol (colluvi – loamic)										
0–30	5.8	4.8	6.35	0.69	9.20	16.94	0.07	0.01	1.32	7.65	9.05	-	32.61	27.75	0.03	0.04	0.32	0.76

(0.09%) to very high (1.7%) with most samples having high TN concentration (Table 5). High N concentration is associated with high organic matter contents at surface horizons (Whitbread, 1995). The N concentrations in the profiles decrease with depth.

Available phosphorous

Available P values are low, ranging between 7.13 and 19.76 mg kg^{-1} (Table 5). These low P concentrations are associated with the acidic nature of the soils: all the three soils studied are acidic with pH values < 6.5 (4.8 to 6.2). At these pH values, Fe, Al and manganese (Mn) are highly soluble. Because the ionic form in which P exists in this pH range is the phosphate ($H_2PO_4^-$) (Harrison, 2007), those cations will react with the phosphate ions to form hydroxy-phosphate which is insoluble, becoming unavailable for plant uptake.

Amorphous iron and aluminium

Amorphous Fe and Al are important soil parameters which can inform on the structural stability of soils, especially aggregate stability (Stefanou and Papazafeiriou, 2013). They can contribute to the fragic nature of some soil horizons (Steele et al., 1969), inform on the rate of weathering (Degörski, 2011), and can also be used as a criteria for soil classification (FAO, 2014). Generally, Fe and Al oxides contribute to the formation of compacted soil horizons (hardpans, duripans, hard settings) which are recognized as genetic soil horizons (Soil Survey Staff, 1999). Fe oxides and Al oxides are not by themselves cohesive or coagulating agents of soil particles, though they play a significant role in cementing some soils (Stefanou and Papazafeiriou, 2013).

For the three soils studied, concentrations of amorphous Fe ranged from 0.06 to 1.35%, while concentrations of amorphous Al range between 0.16 and 1.01% (Table 5). These concentrations are high enough to have an effect on the structural stability of soils. According to Stefanou and Papazafeiriou (2013), a concentration of about 1% amorphous Fe may cause a the occurrence of progressive weathering of parent materials, but the weathering is not advanced enough to qualify the soils as old penetration resistance of about 7 MPa, while a concentration of about 1 % amorphous Al may cause a root penetration resistance of about 34 MPa. The above concentration ranges of amorphous Al and Fe indicated (Degörski, 2011). The soils have vitric materials indicated by the (Al+1/2Fe)o values which are greater than 0.4% (Olafur, 2008). The presence of these vitric materials is in conformity with the high sand contents (Table 4).

Electrical conductivity

Electrical conductivit (EC) is low in all soils. Values for EC ranged from 0.02 to 0.29 mS/cm (Table 5). According to Richards (1954), the EC of these soils belongs to "Class A". This range of EC reflects osmotic potentials of 0 to 70 KPa and, further indicates that with respect to crop salt tolerance, the crops are sensitive (Richards, 1954). In all profiles, EC values decrease with depth. Generally, EC is related to soil texture. EC values are generally higher for fine-textured soils than for coarse-textured soils (Sudduth et al., 2004). Field descriptions and observations of the soils indicated that surface horizons were more fine-textured as compared to subsurface horizons. This explains why EC values decrease with depth.

Cation exchange capacity

Cation exchange capacity is high in all soils (Table 5). CEC ranged between 20.5 and 38.08 cmol(+)kg^{-1} soil. The CEC values are higher in surface horizons and decrease with depth. The high CEC values may be associated with the high organic matter contents in these soils as organic matter is a source of negative charge in soils. In similar soils around mount Cameroon and in the Mungo (close to Tombel), higher values of CEC (35 to 55 cmol(+)kg^{-1}, with organic matter contents between 6 and 10%) have been reported (Yerima and Van Ranst, 2005b).

Exchangeable bases

Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+) in all soil profiles showed the following trend: Ca^{2+} > Mg^{2+} > K^+ and Na^+. This is a general observation in most soils (Kim, 1998). Equally, Na^+ is more labile than the other elements (Yerima and Van Ranst, 2005a). Quantitatively, the concentrations of these cations vary as follows: Ca^{2+} (between 2.0 and 10.64 cmol(+)kg^{-1} soil), Mg^{2+} (between 0.08 and 2.56 cmol(+)kg^{-1} soil), K^+ (between 0.01 and 0.31 cmol(+)kg^{-1} soil) and Na^+ (between 0.01 and 0.05 meq/100 g soil). These concentrations are quite low (especially for Na^+ and K^+) not only because of the porous nature of the soils that are prone to base leaching but equally to the prevalence of pH values of less than 6, where these cations are deficient (Kim, 1998). Harrison (2007) also reported a decrease of soil concentrations of Ca^{2+}, Mg^{2+}, N and sulphur (s) with increasing soil acidity, and unavailability of P under low and high pH values (below 6 and above 8, respectively). Nonetheless, Ca^{2+} and Mg^{2+} are in moderate concentrations with respect to critical fertility levels and indicate the presence of considerable amounts of weatherable minerals.

Evaluation of land suitability

Climatic and land suitability indices for maize, beans and Irish potatoes are presented in Tables 6 and 7. The soils of Nyassosso are marginally suitable for rain-fed

Table 6. Evaluation of climatic characteristics for beans, maize and Irish potatoes in the three sites.

Climatic characteristic	NYASSOSSO						MBULE						TOMBEL					
	Maize		Beans		Irish potato		Maize		Beans		Irish potato		Maize		Beans		Irish potato	
	V	Par V	V	Par V	V	Par V	V	Par V	V	Par V	V	Par V	V	Par V	V	Par V	V	Par V
Precipitation of growing cycle (mm)	1061	90.36	712	67	1060	100	1061	90.36	712	67	1061	100	1061	90.36	712	67	1061	100
Precipitation of the 1st month (mm)	221	85.14	-	-	221	100	221	85.14	-	-	221	100	221	85.14	-	-	221	100
Precipitation of the 2nd month (mm)	216	98.44	-	-	216	100	216	98.44	-	-	216	100	216	98.44	-	-	216	100
Precipitation of the 3rd month (mm)	274	90.25	-	-	274	100	274	90.25	-	-	274	100	274	90.25	-	-	274	100
Precipitation of the 4th month (mm)	349	73.91	-	-	349	95	349	73.91	-	-	349	95	349	73.91	-	-	349	95
Mean temp. growing cycle (°C)	21.6	86	21.6	77.5	21.6	91	23.6	98	23.6	86	23.6	86.3	25.6	99.5	25.6	73.3	25.6	73.3
Mean min. temp. growing cycle (°C)	21.3	85.75	21.3	91.75	-	-	23.3	93.8	23.3	86.75	-	-	25.3	65.42	25.5	57.5	-	-
Relative humidity of developmental stage (%)	86	88	86	78.3	-	-	86	88	86	78.3	-	-	86	88	86	78.3	-	-
Average daylength of growing cycle (h)	-	-	-	-	14.3	97.16	-	-	-	-	14.3	97.16	-	-	-	-	14.3	97.16
Relative humidity of maturity stage (%)	87	80	86	-	-	-	87	80	86	-	-	-	87	80	86	-	-	-
Climatic Index (CI),		50.7		55.68		83.99		55.46		45.12		79.66		38.68		30.17		67.66
Climatic Rating (CR)		62.3		66.78		92.26		66.58		57.23		88.36		51.41		43.82		77.56

V= Value, Par V= parametric value.

Table 7. Evaluation of land and soil characteristics for beans, maize and Irish potatoes for each of the three sites.

Landscape and Soil characteristics	*Nyassosso* : Epidystri – Andic Cambisol (humi – loamic)						*Mbule :* Epidystri – Skeletic Andosol (Colluvi – loamic)						*Tombel: Dystri – Skeletic Andosol (Colluvi – loamic)*					
	Maize		Beans		Irish potato		Maize		Beans		Irish potato		Maize		Beans		Irish potato	
	V	Par V	V	Par V	V	Par V	V	Par V	V	Par V	V	Par V	V	Par V	V	Par V	V	Par V
Topography (t)																		
Slope (%) (l)	2-5	95	2-5	95	2-5	95	10-15	72.5	10-15	72.5	10-15	72.5	5-10	90	5-10	90	5-10	90

Table 7. Contd.

Wetness (w)																		
Flooding	None	100	None	100	None	100	None	100	None	100	None	100	None	100	None	100	None	100
Drainage	Good	100	Good	100	Good	100	Good	100	Good	100	Good	100	Good	100	Good	100	Good	100
Physical soil characteristics (s)																		
Texture/structure	SL	72.5	SL	72.5	SL	90	SCL	90	SCL	90	SCL	100	SCL	90	SCL	90	SCL	100
Coarse fragments (volume %)	15	95	15	95	15	95	27	76.25	27	76.25	27	76.25	35	60	35	60	35	60
Soil depth (cm)	>100	100	>100	100	>100	100	>100	100	>100	100	>100	100	>100	100	>100	100	>100	100
Soil fertility (f)																		
CEC (meq/100g)	24.53	100	24.53	100	24.53	100	28.08	100	28.08	100	28.08	100	32.61	100	32.61	100	32.61	100
BS (%)	10.88	50.9	10.88	50.9	10.88	67.7	30.45	77.4	30.45	77.4	30.45	81.8	27.75	72.9	27.75	72.9	27.75	79.8
pH-H_2O	5.3	50.0	5.3	46.6	5.3	66.3	5.7	87.5	5.7	76.6	5.7	87.5	5.8	90.0	5.8	85.5	5.8	90.0
OC (%)	4.86	100	4.86	100	4.86	100	4.67	100	4.67	100	4.67	100	6.35	100	6.35	100	6.35	100
Salinity and sodicity (n)																		
ESP (%)	0.12	100	0.12	100	0.12	100	0.14	100	0.14	100	0.14	100	0.03	100	0.03	100	0.03	100
EC (mmhos/cm)	0.09	100	0.09	100	0.09	100	0.09	100	0.09	100	0.09	100	0.03	100	0.03	100	0.03	100
Land index	20.4		20.4		49.7		25.6		21.8		40.0		18.2		15.5		33.4	
Suitability class	S3/N,f		S3/N,f		S2/S3,f		S3		S3/N,f		S2/S3		N,s,f		N,s,f		S3	

V= Value, Par V= parametric value.

cultivation of Irish potatoes, but not suitable for the cultivation of maize and beans due to fertility constraints, notably low base saturation and low pH (Table 7). At these low pH values, Al becomes soluble, thus occupying exchange sites. These bases can however be corrected through liming and fertilization (especially organic amendments). The land indices of 49.7, 20.4 and 20.4 for Irish potatoes, beans and maize, respectively indicate that soils of Nyassosso are most suitable for the cultivation of Irish potatoes, followed by beans and maize. Soils in the Mbule series are marginally suitable for maize and Irish potatoes cultivation but not suitable for the cultivation of beans due to fertility constraints (low BS and low pH). The land indices of 40.0, 25.6 and 21.8 for Irish potatoes, maize and beans, respectively indicate that soils are more suitable for Irish potatoes cultivation, followed by maize, and then beans. In the Tombel series, land indices of 33.4, 18.2 and 15.5 for Irish potatoes, maize, and beans, respectively, indicate that soils in Tombel are marginally suitable for rain-fed cultivation of Irish potatoes but currently not suitable for maize and beans.

In Tombel, the main constraint is the high amount of gravel in the soils which will certainly have an impact on root development associated with low water and nutrient retention, high rate of organic matter mineralization, high base leaching, and low stability, especially for maize. This limitation can however be managed by selecting the appropriate sites where surface horizons have low gravel contents. Nyassosso and Mbule will thus be more appropriate.

From Nyassosso (900 m above sea level) to Mbule (700 m above sea level) and Tombel (500 m above sea level), there was a progressive decrease in land indices for Irish potatoes.

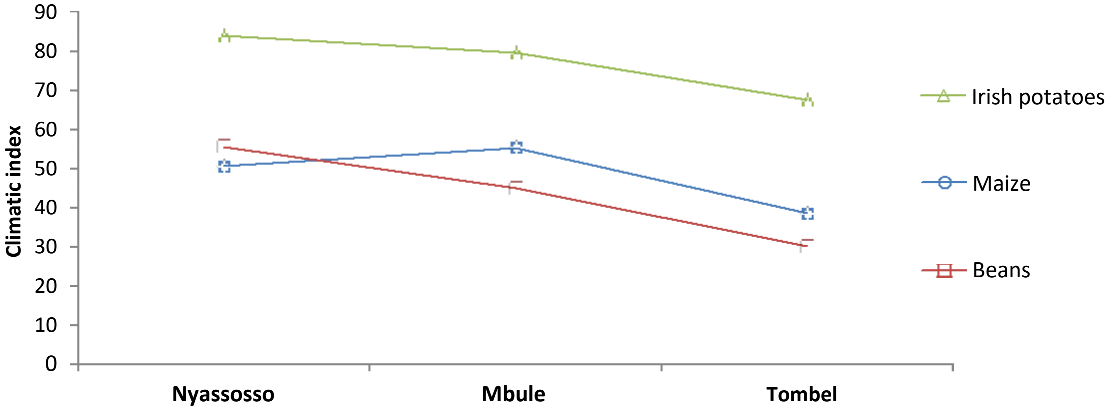

Figure 3. Variation of climatic index along a toposequence for rain-fed cultivation of Irish potatoes, maize and beans.

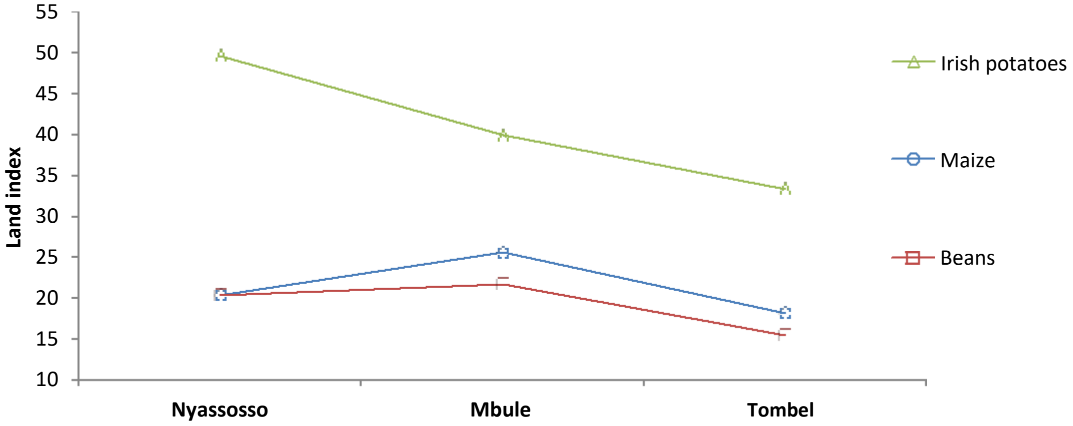

Figure 4. Variation of land index along a toposequence for rain-fed cultivation of Irish potatoes, maize and beans.

Therefore, a better performance of Irish potatoes will be observed at higher altitude and/or lower temperature. For maize and beans however, land indices indicated that best crops performance will be observed in the Mbule series.

Figures 3 and 4 show that performance of maize, beans, and Irish potatoes vary along a toposequence. Climatic indices (Table 6) indicated that best performance of these crops will be observed at higher altitudes and lower temperatures rather than at lower altitudes where the temperatures are higher. Cultivation of these crops has given good results on the western highlands of Cameroon, precisely on the Bambouto Mountains with varied soil types and lower temperatures (Tsozué et al., 2015).

Conclusions

Although, soils of the western slopes of Kupe mountain show soil properties that are conducive for crop production (high organic matter content and low bulk density), the coarse-textured nature of these soils, and the high humidity (higher elevations) and higher temperature (lower elevation) prevailing in the areas may increase the mineralization of organic matter leading to the fast release of nutrient elements which are quickly leached due to the high rainfall; especially, in Tombel, where temperature is higher. The soils in the study area are only marginally suitable for the rain-fed cultivation of corn, beans and Irish potatoes due to climatic limitations, soil acidity and stoniness (coarse fragments). Nevertheless, management practices such as the use of organ manures, liming and chemical fertilizers can readily mitigate the limitations.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Akinrinde EA (2004). Soils: Nature, Fertility Conservation and Management. AMS Publishing, Austria P 116.

Beernaert F, Bitondo D (1993). Land evaluation manual. CUDs Dschang, Cameroon P 398.

Bouyoucos GJ (1962). Hydrometer method improved for making particle size analysis of soil. Agron. J. 54:464-465.

Brady NC (1974). The Nature and Properties of Soils (8th edn). Macmillan Publishing, New York, NY.

Brady NC (1990). The nature and properties of soils (10th edn). Macmillan Publishing, New York, NY.

Bremner J (2012). Population and food security: Africa's challenge. Population reference bureau: Washington, DC 20009 USA.

Cass A (1998). Measuring and managing chemical impediments to growth. Aust. Grapegrower Winemaker. 415:13-16.

Degörski M (2011). The relationships between different forms of iron and aluminium in soils as indicators of soil cover development on India's Cherrapunji spur (Meghalaya plateau). Geogr. Polonica 84(1):61-73.

Euroconsult (1989). Agricultural compendium for rural development in the tropics and the subtropics. Elsevier: Amsterdam.

FAO (2006a). Plant nutrition for food security, a guide for integrated nutrient management. FAO fertilizer and plant nutrition bulletin. No. 16. FAO: Rome.

FAO (2006b). Guidelines for soil description (4th edn). FAO: Rome. FAO

(2014). World reference base for soil resources. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome P. 181.

Gartlan S (1989). La Conservation des Ecosystèmes forestiers du Cameroun. IUCN: Cambridge P 186.

Gong J, Liu Y, Chen W (2012). Land suitability evaluation for development using a matter-element model: A case study in Zengcheng, Guangzhou, China. Land Use Policy 29:464-472.

Harrison MR (2007). Principles of environmental chemistry. RSC Publishing, UK. P. 363.

Hazelton P, Murphy B (2007). Interpreting soil test results. What do all the numbers mean? CSIRO Publishing, Victoria.

Jensen ME, Burman RD, Allen RG (1990). Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practices No. 70. Am. Soc. Civil Engrs: New York.

Kim HT (1998). Principles of soil chemistry (3rd edn). Marcel Dekker, New York P 521.

Kubotera H, Yamada I (1995). Characteristics of induration of tephra-derived soils in Kyushu. 1. Morphological, physical, chemical and mineralogical properties of "Nigatsuchi" in the western forest area of Aso volcano in Kumamoto Prefecture. Pedologist 39:84-98.

Nahusenay A, Kibebew K (2015). Land suitability evaluation in Wadla Delanta Massif of north central highlands of Ethiopia for rainfed crop production. Afr. J. Agric. Res. 10(13):1595-1611.

Nkonya E, Mirzabaev A, Von Braun J (2016). Economics of Land Degradation and Improvement: An Introduction and Overview. In Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development, Nkonya E, Mirzabaev A, Von Braun J (eds). Springer, Cham, Heidelberg, New York, Dordrecht, London pp. 1-14.

Olafur A (2008). Andosols. In Encyclopedia of Soil Science, Chesworth W (ed). Springer pp. 39-46.

Pauwels JM, Van Ranst E, Verloo M, Mvondo Ze A (1992). Manuel de laboratoire de pédologie . Méthodes d'analyses des sols et des plantes, équipement, gestion de stocks de verrerie et de produits chimiques. Publications Agricoles No. 28, AGCD, Bruxelles, Belgium P 180.

Penman HL (1948). Natural evaporation from open water, bare soil, and grass. Royal Society of London Proceedings, Series A. 193:120-145.

Richards LA (1954). Diagnosis and Improvement of Saline and Alkali Soils. USDA Agriculture Handbook 60. Washington DC.

Sanchez PA (2005). Reducing Hunger in Tropical Africa while Coping with Climate Change. In: Climate change and global food security (Lal R, Stewart BA, Uphoff N, Hansen DO, eds). Taylor and Francis, New York.

Shoji S, Takahashi T (2002). Environmental and agricultural significance of volcanic tephra soils. Global Environ. Res. 6:113-135.

Soil Survey Staff (1999). Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDASCS Agric. Handbook. 436. U.S. Gov. Print. Office, Washington D.C.

Steele F, Daniels RB, Gamble EE, Nelson LA (1969). Fragipan horizons and Be masses in the Middle Coastal Plain of North Central North Carolina. Soil Sci. Soc. Am. Proc. 33:752-755.

Stefanou S, Papazafeiriou AZ (2013). Effects of iron and aluminium oxides and clay content on penetration resistance of five Greek soils. Eur. J. Soil Sci. 2:122-130.

Sudduth KA, Kitchen NR, Wiebold WJ, Batchelor WD, Bollero GA, Bullock DJ, Clay DE, Palm HL, Pierce FJ , Schuler RT, Thelen KD (2004). Relating apparent electrical conductivity to soil properties across the north-central USA. Comput. Electron. Agric. 46:263-283.

Sys C, Van Ranst E, Debaveye J (1991). Land evaluation. Part 1: Principles in land evaluation and crop production calculation. General Administration for development cooperation. Agric. Publ. No 7, Brussels Belgium.

Sys C, Van Ranst E, Debaveye J (1993). Land evaluation. Part 3: Crop Requirements. International Training Center for Post Graduate Soil Scientists. Ghent University. Ghent, Belgium.

Tematio P, Kengni L, Bitom D, Hodson, Fopoussi JC, Leumbe O, Mpakam HG, Tsozue D (2004). Soils and their distribution on Bambouto volcanic mountain, West Cameroon highland, Central Africa. J. Afr. Earth Sci. 39:447-457.

Tsozué D, Azinwi TP, Ndaka MB (2015). Morphology, Physicochemical Characteristics and Land Suitability in the Western Highlands of Cameroon. Int. J. Plant Soil Sci. 7(1):29-44.

Whitbread AM (1995). Soil Organic Matter: Its Fractionation and Role in Soil Structure. ACIAR Proc. P 56.

Yerima BPK, Van Ranst E (2005a). Introduction to soil science: Soils of the tropics. Trafford Publishing: Canada P 397.

Yerima BPK, Van Ranst E (2005b). Major soil classification systems used in the tropics: Soils of Cameroon. Trafford Publishing, Canada P 282.