International Journal of Plant & Soil Science
7(1): 29-44, 2015; Article no.IJPSS.2015.128
ISSN: 2320-7035

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Morphology, Physicochemical Characteristics and Land Suitability in the Western Highlands of Cameroon

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2015/17147
Editor(s):
(1) Eliana L. Tassi, Institute of Ecosystem Studies, National Research Council (ISE-CNR), Italy.
Reviewers:
(1) Anonymous, Turkey.
(2) Anonymous, South Africa.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=1093&id=24&aid=8789

Original Research Article

Received 27th February 2015
Accepted 27th March 2015
Published 14th April 2015

ABSTRACT

The aim of the study was to evaluate the morphology and physicochemical properties of soils and their suitability to potatoes, maize and beans, in order to contribute to stop rural migration, prevent conflicts between farmers and breeders and contribute to the increase of agricultural yields in the eastern slope of the Bambouto Mountain, Cameroon. Morphologically, the studied soil profiles are poorly or more developed, characterized respectively by AC or ABC horizon sequences. All the soil samples recorded acidic pH (4.8 to 5.5) except in the Bawa and in Zavion footslope where this pH is slightly acidic (6.0 to 6.2). Nitrogen contents are low to medium (0.04 to 0.225), except in midslope and footslope of Zavion site where these contents are very high (0.406 and 0.436% respectively). Organic matter contents increase from the Medji (1.42%) site to Zavion site (9.84%). High content of organic matter in Bawa located at the same altitude as Medji is related to the basaltic bedrock which glasses weathering might induce increase of organic matter content, while high content in Zavion might be mostly related to the increase in altitude and the decrease of

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temperature which slacks up microorganism activities. Phosphorous level is very low and largely under the critical limit (20 ppm) for all the study sites. Calcium is the dominant exchangeable cation, with contents ranging between 0.13 and 7.53 cmol(+)/kg of soil. The cation exchange capacity varied between 2.03 and 29.59 cmol(+)/kg of soil. Base saturation percentage fluctuates from 11.80 to 39.70%. The production of bean, maize and potatoes in the study sites is limited due to high rainfall and wetness, high slope gradient and soil fertility problems which could respectively be solved by promoting crops cultivation at the end of the raining season, terracing of arable land and fertilization and liming.

Keywords: Morphology; physicochemical characteristics; land suitability; Bambouto Mountain; Cameroon.

1. INTRODUCTION

Environmental degradation is of particular concern in many parts of the world [1]. Rapid population growth and declining agricultural productivity affect the livelihoods and very survival of millions of rural households throughout sub-Sahara Africa [2]. Soil nutrient depletion in smallholding farming systems is recognized as a causal force leading to food insecurity and rural poverty in Africa [3,4]. Prima facie, loss of sustainability seems linked to the attitude of rural people towards land resources [1]. Villagers are often considered to be placing their own short-term survival ahead of long-term land resource sustainability [5,1]. The increased needs of a rising population are regarded as particularly disruptive for the environment since the level of resources per capita declines [1]. Soil fertility declines when its nutrient content diminishes, and its quality to meet plant requirements is lowered. Land use and management influence most of the agriculturally relevant soil morphological, physical, chemical and biological characteristics [6-10], leading thus to land degradation. It may appear in many forms such as erosion, soil compaction or surface sealing, decline in vegetation cover or diversity, nutrient depletion and low fertility status, due mostly to poor management, inappropriate land use or lack of nutrient inputs [11-15,1,16]. These different forms of land degradation lead to inefficient exploitation of natural resources, destruction of land resources, poverty and other social problems and even to the destruction of civilization [11,14,15].

The challenge to any project with an objective to improve the productivity of the area is to have baseline on land productivity and identify soil-related constraints in different zones or ecosystems [17]. In the eastern slope of the Bambouto Mountain, Cameroon, populations are concentrated mainly between 1400 and 1800 m asl, with a density of about 120 inhabitants/km^2. The high population pressure and the exposition of this slope to the harmattan wind which blows from the North East are essential causes of land degradation. This explains the poor agricultural yields, the extension of cultivated areas, the movement of populations towards more fertile soils in the upper part of the mountain formerly reserved to pasturage mainly for potatoes or other area such as Noun plain for maize and beans, and rural migration. Ngoufo [18] reported that in 1968, more than 50% of the eastern slope of the Bambouto Mountain was occupied by pasturage and today only some rare pasturage relicts subsist in the upper zone of the massive, above 2000 m asl. The entire slope is now colonized and even all the Bambouto Mountain, reaching his summit at 2740 m asl. Consequently, this situation gives rise to conflicts between farmers and breeders. Sustainability of this ecosystem productivity and biodiversity requires then quantification of quality and quantity of natural resources and their suitability for a range of land use in the planning process of future rural activities [19,20]. Globally, less pedological research has occurred on the Bambouto Mountain and especially in his eastern slope [21-30]. But, no study devoted to land degradation has been done on the soils developed between 1400 and 1800 m asl known as part of the Bamiléké plateau which are suggested to a decline of fertility and nutrients depletion due to high population pressure, and dry tone related to the influence of harmattan. Thus, this study was conducted to evaluate the morphology and physicochemical properties of soils and their suitability to potatoes, maize and beans, in order to contribute to stop rural migration, prevent conflicts between farmers and breeders and contribute to the increase of agricultural yields in the eastern slope of the Bambouto Mountain.

2. MATERIALS AND METHODS

2.1 Study Sites

The eastern slope of the Bambouto massive covers about 261 km^2. It is located globally between 5º37' and 5º45' N, and 10º04' and 10º15' E, and limited in the East by the Noun plain and in the West by the calderas (Fig. 1). It is organized into low, moderate and high hills which are repeated in the landscape, separated by large and narrow valleys [31,32]. The climate is subtropical, transformed by altitude into an altitude tropical climate [32]. Globally, the eastern slope of the Bambouto Mountain is dominated by a dry tone, due to harmattan which blows from the northeast. This wind is accompanied by dry and persistent mist which the thickness has exceeded 3500 m asl in 1983 [31]. The original vegetation between 1400 and 1600 m asl was a forest borderline savannah (mainly *Pennisetum purpureum* and *Imperata cylindrica*) at the base follow by submontane and montane strata (*Albizzia gunnifera*, *Carapa grandiflora* and *Syzigium standtii*) towards high altitude [33]. Azonal edaphic formations are observed in swampy valleys. They are mainly *Cyathae maniana* and *Raphia vinefera* [33]. Globally, natural vegetation consists of typical tropical species but strongly anthropised. The bed rock is constituted of basalts, trachytes and granites. Details of physical characteristics of each study site are resumed in Table 1.

2.2 Field Soil Description and Sampling

Three study sites sufficiently representative of the physical environment of the study area were selected for detailed study, after cartographic and bibliographic documents analysis, and a reconnaissance survey in the field. Drills were made manually along a dense network of 20 to 50 m wide. This helped to define the major groups of soil on the basis of some morphological profile characteristics (colour, texture, formed elements ...) and to identify the points of implantation of soil pits along a representative toposequence of each site for detailed study. The pits were dug manually at three different topographic positions of the toposequence, the summit, midslope and footslope, according to the variability of the soil morphology (Table 1). These pits have a surface area measuring 1.5 m x 1 m, with a depth of 1.5 m maximum when the appearance of the bedrock allows. The description of the soil profiles was done on the walls of each pit, according to the methods of Baise [34]. The main search characters were colour, thickness of horizons, coarse elements, texture, structure, consistency and boundaries between horizons. Disturbed samples of about one-half kilogram were later taken and preserved in polyethylene bags for later laboratory analysis.

2.3 Laboratory Analysis

Different analyses were carried out in the laboratory. These include particle size distribution, organic carbon, acidity, exchangeable cations, cation exchange capacity, exchangeable aluminium, total nitrogen and available phosphorus. Particle size was determined using the Robinson pipette method after pretreatment of soil samples with H_2O_2 to remove organic matter (OM), using sodium hexametaphosphate $(NaPO_3)_6$ as dispersal agent. The quantity of total nitrogen was evaluated by titration after mineralisation of organic matter and distillation. The cation exchange capacity was also evaluated by titration after qualitative desorption by K^+ and distillation. Exchangeable cations are shifted by ammonium acetate (CH_3COONH_4) at pH 7. The proportions of K^+ and Na^+ were evaluated by flame photometry. Those of Ca^{2+} and Mg^{2+} were determined by complexometry. The available phosphorus was determined by the Bray 2 method, which combines extraction of phosphorus in acid medium and their complexation with ammonium fluoride (NH_4F). The quantity of available phosphorus was obtained by spectrophotometry in the presence of blue molybdenum (MoO_3). The proportion of organic carbon was obtained after oxidation in a highly acid medium (H_2SO_4) with potassium dichromate ($K_2Cr_2O_7$). Organic matter (OM) was obtained from organic carbon (C) using the Sprengel factor (OM= Cx1.724) [35]. The bases saturation corresponds to the ratio of the sum of exchangeable cations (S) and cations exchange capacity (CEC). The exchangeable aluminium was extracted in a solution of potassium chloride 1M, and evaluated by colourimetry with the violet pyrocathecol method (VPC). Aluminic toxicity is defined by the Kamprath [36]: $m = \frac{Al}{Al + S} \times 100$.

Comments of physicochemical data of soil were done according to critical values of nutrients and soil properties in Table 2, adapted from Tabi et al. [28] and Euroconsult [37].

In order to identify the soil or the climatic parameters which limited growth and production of the main crops of the area (beans, potatoes and maize) and favour rural migration or conflicts, soils were evaluated for beans, potatoes and maize following the method of Sys et al. [38-40]. Soils' suitability for beans, potatoes and maize was classified as highly (S1), moderately (S2), marginally (S3), actually not but potentially suitable (N1) and actually and potentially not suitable (N2), using simple limitation and parametric methods.

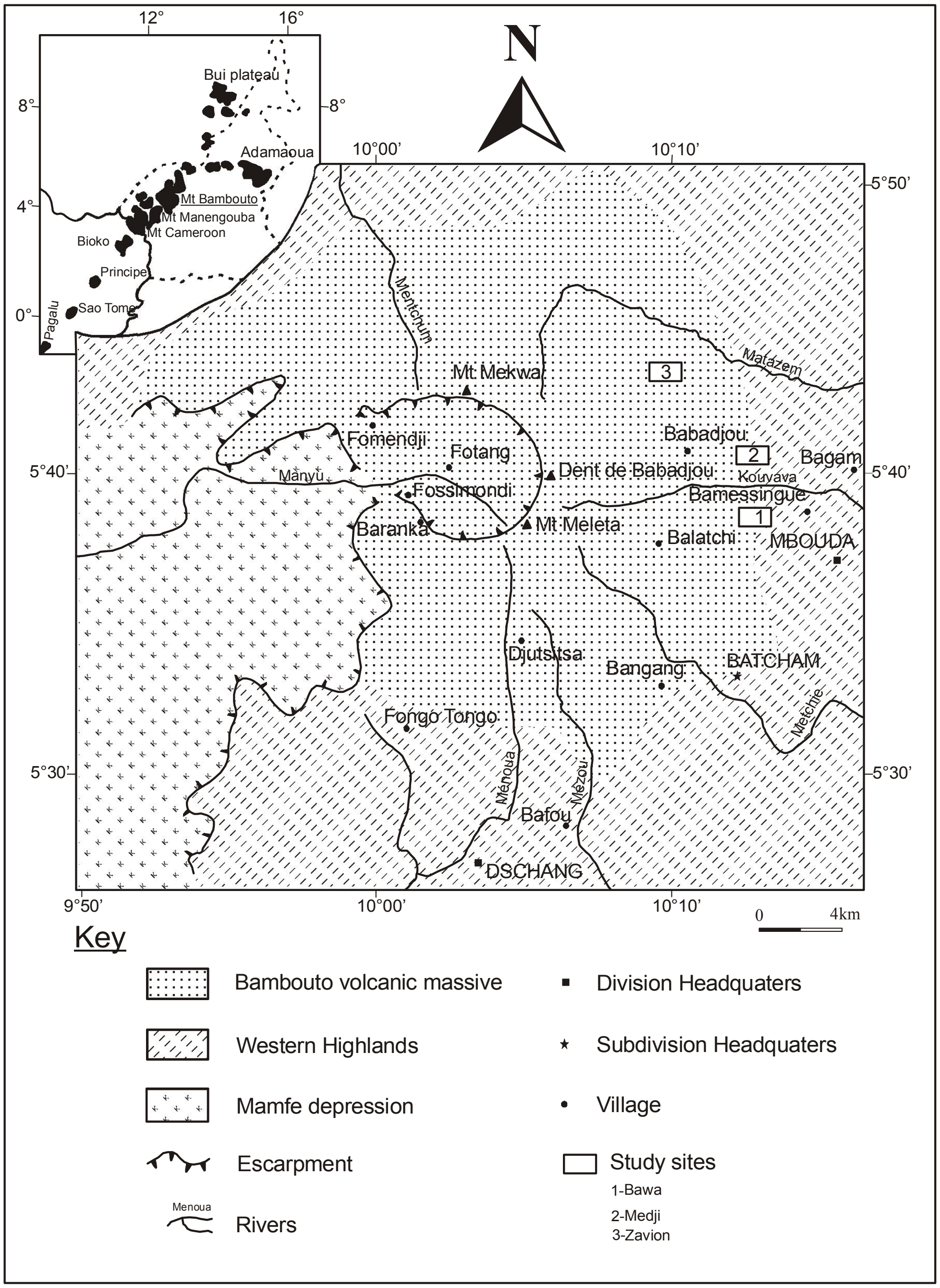

Fig. 1. Location of the study sites

Table 1. Characteristics of the studied site and soils

		Site characteristics		
		Medji	**Bawa**	**Zavion**
Location		**Babadjou village**	**Bamessingue village**	**Babadjou village**
Area (km^2)		**3**	**3**	**6**
Mean altitude of the site (m asl)		**1500**	**1500**	**1750**
Morphology of the site		Microwatershed with stretched interfluves convex summit and flat swampy valleys	Microwatershed with stretched interfluves, rounded and flat summit, convexo-concave slope, flat and large valleys	Microwatershed with stretched interfluves, presence of isolated rounded and flat summit , convex slope with rock escarpments, flat and narrow valleys
Slope gradient (%)		0 – 25	5 – 40	10 – 40
Bedrock		Leucocrate granite with quartz, orthose and biotite	Aphyric basalt with dark color	Trachyte with gray color
vegetation		Herbaceous plant cover on the interfluve and raphia in the valleys	Herbaceous plant cover on the interfluve and raphia in the valleys	Herbaceous plant cover on the interfluve and raphia in the valleys
Climate	Rainfall (mm/year)	1770	1722.8	1729
(Altitude subtropical)	Temperature (°C)	21,6	21,6	17,7

Table 2. Critical values of nutrients and soil properties

Properties	**Critical levels**				
	Very low	**Low**	**medium**	**high**	**Very high**
OM %	< 1	1-2	2-4.2	4.2-6	>6
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 cmol$^+$ kg^{-1}	< 2	2-5	5-10	10-20	> 20
Mg cmol$^+$ kg^{-1}	< 0.5	0.5-1.5	1.5-3	3-8	>8
K cmol$^+$ kg^{-1}	< 0.1	0.1-0.3	0.3-0.6	0.6-1.2	>1.2
Na cmol$^+$ kg^{-1}	< 0.1	0.1-0.3	0.3-0.7	0.7-2.0	>2.0
P mg kg^{-1}	< 7	7-16	16-46	> 46	-
pH	5.3-6.0 = moderately acid; 6.0-7.0 = slightly acid; 7.0-8.5 moderately alkaline				
m %	< 10	10-25	25-35	35-45	> 45
CEC cmol+ kg^{-1}	< 6	6-12	12-25	25-40	> 40
S/CEC %	0-20	21-40	41-60	61-80	81-100

Adapted from Tabi et al. [28] and Euroconsult [37]

3. RESULTS AND DISCUSSION

3.1 Morphological Characteristics and Distribution of Soils

Morphologically, the study soils are poorly developed as indicated by their AC profiles or more developed, as shown by their ABC profiles. In detail, there are some differences from one site to another. Morphological characteristics of soils are summarized in Table 3.

In Medji which is located at 1500 m asl (Table 1), three landscape positions were identified, corresponding to three types of soil profiles, developed on granite of Precambrian age (Table 3 and Fig. 2a). In the summit, the soil profile has a thickness of about 40 cm. This weakly thickness is due to the low residence time of water, consecutively to the convexity of the summit which does not allow deeply weathering, leading to the formation of AC profile. In the midslope, the slope gradient is low and the slope globally concave. Consequently, the residence time of water is high, leading thus to the development of a thick red sandy clay B horizon (thickness>100 m) under the Ap horizon. In the footslope, water table is near the surface, and the valley is flat and swampy. The fluctuation of water table within clayey materials at the base of the toposequence provokes constant redistributions of iron, resulting in the differentiation of pseudogleyed (g) and gleyed (G) horizons, characteristic of hydromorphic soils. This genesis of soils along the slope in Medji site and the countdown evolution in the footslope are commonly demonstrated in the tropical zones [41-43]. In the particle distribution size view point, sand is the most important fraction. High quantity of sand fraction here is related to the presence of quartz in the granite as main constituent toward feldspath, which is the most resistant mineral.

In Bawa, the altitude is also 1500 m asl. Soils are developed on cretaceous basalts. Contrary to granite which is constituted of very resistant minerals, the bedrock is constituted of easily weathering minerals. This characteristic, in addition to flat summit and convexo-concave slope, lead to the formation of and Ap (40 cm thick) horizon and a thick red (10YR4/6) moderate subangular blocky horizon (Table 3), and the total absence of AC soil profile in the study site (Fig. 2b). The process is enhanced by high rainfall and temperature, 1722 mm/year and 21ºC respectively. In the footslope, the soil profile is also of ABC type, but with a very thick Ap horizon, 135 cm (Table 3 and Fig. 2b). This horizon is constituted of soil particles removed from the upper part of the interfluves and their redeposit downslope trough erosion, process accelerated by cultivation.

In Zavion, the altitude is 1750 m asl. The bedrock is a trachyte, also of cretaceous age as in Bawa. This rock comes above basalts meaning they are younger. The landscape is almost mountainous. The distribution of soil along the toposequence is presented in Fig. 2c. Slopes in this site are of S type, morphology characteristic of temperate zone. The summit is flat and the residence time of water is high. Consequently, in this part of the sequence, soils are deeply weathering with ABC profile, characterized by a dark brown red (7.5YR3/3) Ap horizon of 40 cm thick, on top of a red (10YR4/6) B horizon with a very coarse subangular blocky structure which thickness is more than 110 cm (Table 3). In the midslope, the slope gradient is high and the residence time of water is very low, leading thus to the differentiation of very poorly developed soil of AC profile type, with very fine and weak granular structure in the dark brown red (7.5YR3/3) Ap horizon of 20 cm thick (Table 3 and Fig. 2c). In the footslope, soil profile are represented by a thick Ap horizon (thickness > 1.50 cm), dark brown red (7.5YR3/3), loose, with very fine and weak granular structure (Table 3 and Fig. 2c). This high thickness is the result of high removing of fine earth in farmland in the upper part of the interfluves and their redeposit in the narrow valleys downslope.

Globally, the morphology of soil profiles in the study sites is of AC or ABC type. The formation of different horizons depends on the nature of the bedrock, the position in the landscape and the water table level in the valleys. The stark contrast between the colours of the surface and the subsurface horizons is very clear in the field. All soils become plastic and sticky when wet but very hard when dry in the C and B, g and G horizons and even in the Ap horizon in the summit of the landscape in Medji and Bawa, and loose in the other Ap horizons. These observations are similar to those obtained in other tropical zone [44]. The blocky structures that is angular and sub-angular blocky especially in subsoil is due to the presence of higher clay fractions [45]. The soil colour varied from dark brown (7.5YR 3/3) to red (10YR 3/6) except in the footslope of the Medji site. Red soil colour may be due to presence of sesquioxides as the colour is the function of chemical and mineralogical composition as well as textural make up of soil and conditioned by topographic position and moisture regime [46].

3.2 Physicochemical Characteristics of Soils

All the profile samples recorded acidic pH (4.8 to 5.5) except in the Bawa and in Zavion footslope where this pH is slightly acidic (6.0 to 6.2) (Table 4), leading therefore to high possibility of aluminium and other heavy metal toxicity [17]. This slightly acidic pH might be attributed to the volcanic nature of the parent rocks due to the release of alkaline elements in the soils. The pH in KCl is lower than the pH_{water} in all profile samples, indicating the presence of variable charge clay surfaces in the study soils [47]. Nitrogen contents are low to medium, except in midslope and footslope of Zavion site where it is very high (0.406 and 0.436% respectively) (Table 4). Low content of nitrogen may be due to rapid mineralization leading to leaching losses [48,17], while high contents might be linked to the influence of altitude. Similarly, organic carbon level in all the sites is more than the critical limit of 2% except for Ap horizon in summit and B horizon in the midslope of the Medji site, B horizon in the summit of the Bawa site and B horizon of the Zavion site. Consequently, organic matter contents follow that of organic carbon and increase from the Medji (1.42%) site to Zavion site (9.84%). High content of organic matter in Bawa (2.42 to 6.51%) located at the same altitude as Medji is related to the basaltic parent rock which glasses weathering might induce increase of organic matter content, while high content in Zavion might be related to the increase in altitude and decrease of temperature which slacks up microorganism activities [49]. Carbon/nitrogen (C/N) ratios vary globally between 13.1 and 19.6, except in the footslope of the Medji site where this value is 9.1 to 9.4 (Table 4). The relatively higher values of C/N ratios suggest low rate of organic matter decomposition and indicate lower rate of mineralization of organic N [47]. Phosphorous level is very low and largely under the critical limit (20 ppm) for all the study sites (0.00 to 5.60 ppm) (Table 4). These low levels of available P may be due to the inherently low P levels of the soil or due to its high P fixation capacity caused by the strongly acidic and moderately acidic soil reactions [47]. The sum of exchangeable bases for all the studied soils ranged between 0.27 and 10.17 cmol(+)/kg of soil (Table 4). Calcium was the dominant exchangeable cation, with contents ranging between 0.13 and 7.53 cmol(+)/kg of soil. It was followed by magnesium (0.08 to 2.50 cmol(+)/kg of soil), while sodium and potassium showed more modest values, 0.005 to 0.054 cmol(+)/kg of soil for sodium, and 0.03 to 0.86 cmol(+)/kg of soil for potassium (Table 4). The cation exchange capacity varied between 2.03 and 29.59 cmol(+)/kg of soil. Base saturation (S/CEC) globally fluctuated from 11.80 to 39.70% (Table 4). Globally, the CEC and total exchangeable bases decreased consistently from the surface to the subsurface B or G horizons (Table 4). The decrease in CEC with depth could be due to the strong association between organic carbon and CEC, as organic matter content also decreased with depth in all pedons [47]. The B horizons showed relatively lower values of CEC and base saturation percentage values lower than 50% suggesting high intensity of weathering and the presence of 1:1 (kaolinitic) type minerals [47]. The base saturation percentage values throughout the studied soils less than 50% could also be due to the high rainfall and intensive cultivation in the study area that enhanced loss of basic cations through leaching and crop harvest [50,9,47]. Aluminium toxicity values are globally low, except in the Ap horizon (65.81% in the summit) and G horizon (40.20% in the footslope) in the site of Medji and the Ap horizon (20%) of the midslope in the site of Zavion (Table 4).

The correlation coefficients of different soil properties examined are presented in Tables 5, 6 and 7. All the significant (*P*= .05) correlation coefficients are upper than 0.9 except between S and CEC in Medji where r=0.882 (Table 6). In addition, a significant negative correlation was noted between N and C/N (r= -0.975, *P*= .05) and between C/N and CEC (r= -0.940, *P*= .05) in Medji (Table 6). There was a significant positive correlation between pH_{H2O} and K^+ (r=0.958, *P*= .05) and S/CEC (r=0.969, *P*= .05) in Bawa (Table 5). The pH_{H2O} was rather significantly correlated with Ca^{2+} (r=0.957, *P*= .05), Mg^{2+} (r=0.991, *P*= .05) and S (r=0.964, *P*= .05) in Zavion (Table 7). In Medji on contrary, there were no significant correlation between pH_{H2O} and any other soil parameter (Table 6). These differences between the three sites might be due to the heterogeneity of soils in relation with the nature of the bedrocks

[49]. The absence of significant correlation between pH_{H2O} and other soil parameters in Medji might be attributed to the acidic nature of the granite which might be the only factor that influences the soil pH. In Bawa, Ca^{2+} was the only exchangeable base which was significantly and positively correlated with a soil parameter (Al^{3+}: r=0.958, *P*= .05; S: r=0.975, *P*= .05) (Table 5). On contrary, in the other two sites, Ca^{2+} and Mg^{2+} were significantly and positively correlated with Al^{3+}, S, S/CEC and S, S/CEC respectively (Tables 6 and 7). In addition, Na^{+} was significantly and positively correlated with S/CEC in Zavion. Globally, except for Mg^{2+} (r=0.985, *P*= .05), organic carbon was not significantly correlated with Ca^{2+}, K^{+} and Na^{+}, suggesting that organic matter is not the main source of the nutrients [51]. Organic carbon and nitrogen were significantly and positively correlated with CEC in all the studied sites, suggesting organic matter to be the main contributor to CEC. Calcium and magnesium correlate positively in Medji and Zavion, indicating the inter-relationship of plant uptake of these bases [51].

3.3 Suitability of Soils for Crop Production

Soil fertility depends on physical, chemical and biological soil properties [52]. It depends not only on parent material but also on land use practice and continuous cultivation without proper management causes nutrient imbalance [52]. The studied soils are widely used for potatoes, maize and beans, three main crops for which people of the studied area went across the region in order to find fertile soils able to produce good yields. The fertility status of these soils was apprehended through land evaluation. This process enables one to identify potential soil fertility constraints to the production of agricultural crops, and thus provides valuable information for the design of appropriate soil management strategies for the sustainable crop production [44].

The summit parts of the study sites and even the midslope part of the Zavion site are actually and potentially not suitable (N2) for bean cultivation due to high slope gradient (Table 8). The footslope is also actually and potentially not suitable (N2) for bean cultivation due to flooding and internal drainage (Table 8). In addition, all the studied soils are marginally suitable for beans cultivation due to the high rainfall. Except the summit part of Bawa site, the studied soils are marginally and even actually and potentially not suitable to beans cultivation due to the problem of soil fertility, generated by an acidic pH.

The study areas' climate is highly suitable for potatoes growth (Table 8). Slope gradient on contrary, constitute a handicap for this crop cultivation in the summit part of Medji and Bawa where soils are actually and potentially not suitable (N2) and in all position in the landscape of Zavion where soils are actually not but potentially suitable (N1) (Table 8). In addition, footslopes are actually and potentially not suitable (N2) due to the wetness. On fertility view point, except for Bawa, the studied soils are marginally not suitable for potatoes mainly due to low soil pH which could have repercussions on base saturation percentage.

The studied soils are globally marginally suitable for the production of maize due to high rainfall. As for bean and potatoes, slope gradient and wetness constitute limitations for its production. The problem of soil fertility is more perceptible only in Medji where soils are actually and potentially not suitable (N2) in the summit and the footslope due to low pH (Table 8).

If the slope gradient is a limitation difficult to overcome which could be solve only by terracing of arable land [2], flooding, internal drainage and precipitations problems could be solve by promoting crops cultivation at the end of the raining season or in the dry season if the soil humidity is sufficient. The problem of acidic pH could be solved by restoration of the cation balance through fertilization and liming. This solution has already been proposed by Verdoodt and Van Ranst [2]. Beernaert and Bitondo [53] suggested a rotation of these three crops after four year in other to avoid nematode infestation.

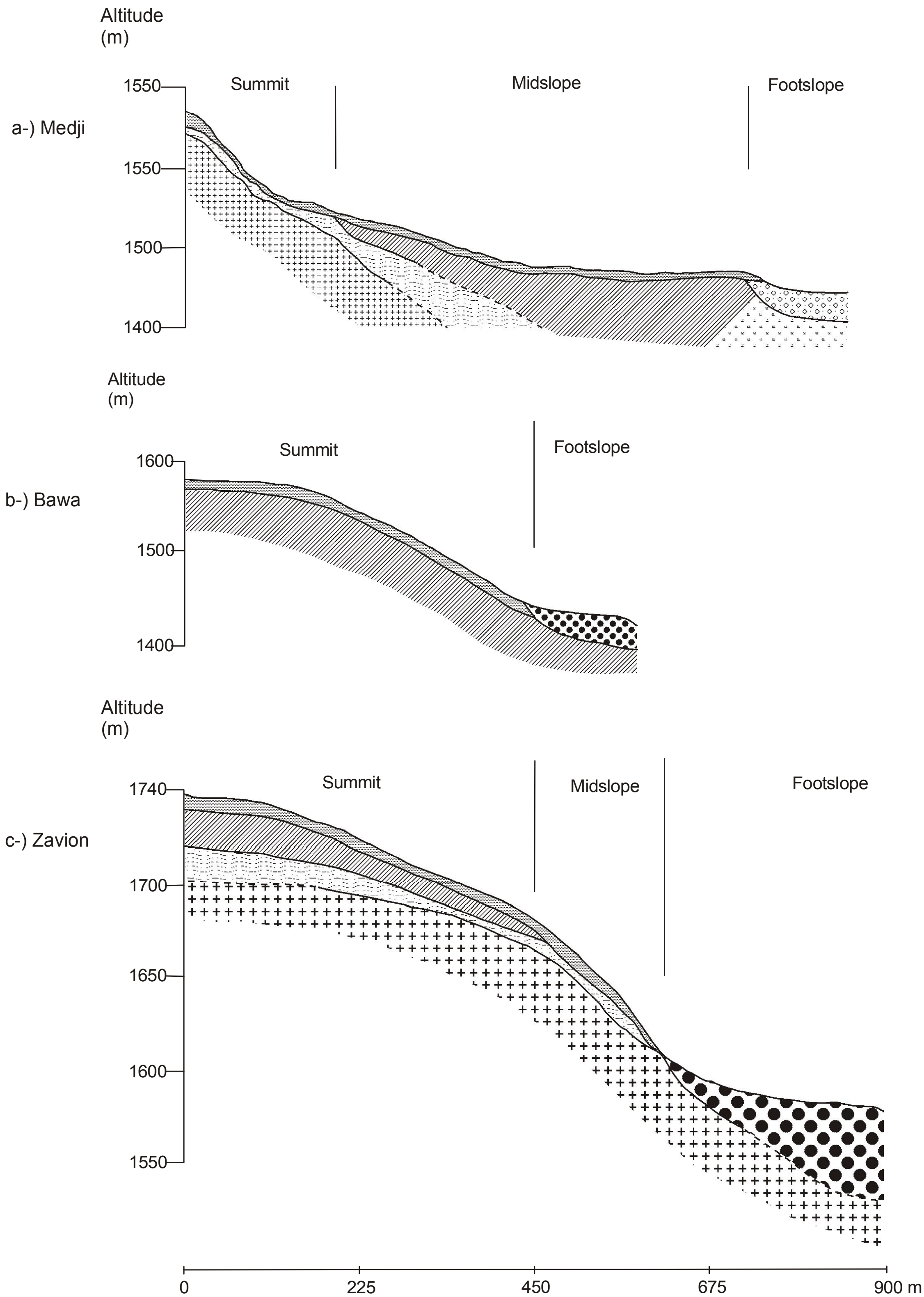

Fig. 2. Variation of soil depth along slopes in the studied sites

Table 3. Morphological and physical characteristics of soils

Site	Position	Horizon	Depth (cm)	Colour (Moist)	Structure	Consistence		Rock fragments	Boundary	Clay (%)	Silt (%)	Sand (%)	Textural class
						Dry	Wet						
Medji	Summit	Ap	0-15	7.5YR3/3	Vf&wg	h	s & p	n	a	33.0	15.6	51.3	Sandy clay loam
		C	15-40	ND	ma	h	S & p	a	g	ND	ND	ND	ND
	Midslope	Ap	0-50	5YR3/4	f&wl	l	s & p	n	g	29.0	16.6	54.3	Sandy clay loam
		B	50-150	10R4/6	vf&wabk	h	s & p	n	g	41.0	12.6	46.3	Sandy clay
	Footslope	g	0-100	7.5YR4/1	f&wl	h	s & p	n	a	35.0	35.6	29.3	Clay loam
		G	100-150	10B4/1	ma	h	s & p	n	a	ND	ND	ND	ND
Bawa	Summit	Ap	0-40	2.5YR3/6	f&wl	h	s & p	n	g	37.0	26.6	36.3	Clay loam
		B	40-150	10R3/6	m&sabk	h	s & p	n	g	74.0	19.6	6.3	Clay
	Footslope	Ap	0-135	2.5YR3/2	vf&ml-g	l	s & p	n	a	29.0	26.6	44.3	Clay loam
		B	135-150	2.5YR3/4	Vc&sabk	h	s & p	n	g	36.0	30.6	33.3	Clay loam
Zavion	Summit	Ap	0-40	7.5YR3/3	f&wl	l	s & p	n	g	ND	ND	ND	ND
		B	40-150	10R4/6	vc&sabk	h	s & p	n	g	60.0	11.3	28.7	Clay
	Midslope	Ap	0-20	7.5YR3/3	vf&wg	l	s & p	v	a	21.0	39.3	39.7	Loam
		C	20-100	ND	ma	h	S & p	a	g	16.0	50.0	34.0	Silt loam
	Footslope	Ap	0-150	7.5YR3/3	vf&wg	l	s & p	n	a	27.0	29.3	43.7	Loam

Soil characteristics

Structure			Consistency		Rock fragments	Horizon boundary
Size	**Type**	**Grade**	**Dry:**	**Wet:**	**n = none (0%)**	**a = abrupt**
vf = very fine (G5 mm)	g = granular	w = weak (peds barely observable)	**l = loose**	**s = sticky**	**m = many (15%–40%)**	**c = clear**
f = fine (5–10 mm)	abk = angular blocky	m = moderate (peds observable)	**s = soft**	**p = plastic**	**v = very few (0%–2%)**	**g= gradual**
m = medium (10–20 mm)	sbk = subangular blocky	s = strong (peds clearly observable)	**h = hard**		**a = abundant (40%–80%)**	**d = diffuse**
c = coarse (20–50mm)	l=lumpy				**c = common (5%–15%)**	
vc = very coarse (>50 mm)	ma=massive				**d = dominant (>80%)**	

ND indicates not determined data

Table 4. Chemical characteristics of soils

Site	Position	Horizon	Depth (cm)	pH_{water}	pH_{KCl}	OC (%)	OM (%)	N (%)	C/N	Avail P (mg/kg)	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	S	CEC	S/CEC (%)	M (%)
											cmol(+)/kg								
Medji	Summit	Ap	0-15	4.9	4.0	1.73	2.94	0.088	19.7	1.77	0.23	0.09	0.20	0.007	1.02	0.53	4.49	11.80	65.81
		C	15-40	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Mid slope	Ap	0-50	5.5	4.4	2.13	3.62	0.135	15.8	3.37	1.20	0.53	0.21	0.007	0.12	1.95	9.30	20.97	5.80
		B	50-150	5.1	4.8	0.83	1.42	0.045	18.5	1.16	0.24	0.15	0.04	0.005	0.00	0.44	3.32	13.25	0.00
	Footslope	g	0-100	5.1	4.4	2.66	4.52	0.283	9.4	1.51	3.49	1.02	0.16	0.020	0.11	4.69	13.83	33.91	2.29
		G	100-150	5.3	4.1	2.59	4.40	0.285	9.1	0.35	1.24	0.25	0.23	0.054	1.19	1.77	11.77	15.04	40.20
Bawa	Summit	Ap	0-40	6.2	5.1	3.83	6.51	0.227	17.1	3.57	6.44	2.16	0.28	0.008	0.51	8.88	22.37	39.70	5.43
		B	40-150	6.1	5.8	1.23	2.12	0.063	19.6	1.00	1.54	0.56	0.09	0.007	0.00	2.19	6.38	34.33	0.00
	Footslope	Ap	0-135	6.0	4.9	3.81	6.48	0.202	18.9	2.64	3.31	2.50	0.03	0.008	0.05	5.85	18.86	31.02	0.85
		B	135-150	6.0	4.9	3.06	5.20	0.174	17.6	1.39	2.18	1.83	0.04	0.016	0.07	4.07	14.54	27.99	1.69
Zavion	Summit	Ap	0-35	5.5	4.9	4.79	8.14	0.282	17.0	0.65	2.52	0.79	0.34	0.010	0.01	3.66	19.95	18.35	0.27
		B	35-150	4.8	4.2	0.52	0.88	0.033	15.8	0.00	0.13	0.08	0.05	0.012	0.00	0.27	2.03	13.20	0.00
	Midslope	Ap	0-20	5.2	4.2	5.62	9.55	0.406	13.8	1.03	1.53	0.43	0.84	0.006	0.74	2.81	22.65	12.41	20.90
		C	20-100	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Fooslope	Ap	0-150	6.0	5.0	5.71	9.84	0.436	13.1	5.60	7.53	1.56	0.86	0.028	0.00	10.17	29.59	34.37	0.00

ND indicates not determined data

Table 5. Pearson correlation matrix for linear relationships between selected soil parameters of Bawa

Variables	pH_{H2O}	pH_{KCl}	OC	N	C/N	P	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	S	CEC	S/CEC
pH_{H2O}	**1**													
pH_{KCl}	0.387	**1**												
OC	-0.016	-0.899	**1**											
N	0.084	-0.875	**0.991***	**1**										
C/N	-0.332	0.630	-0.676	-0.765	**1**									
P	0.500	-0.498	0.826	0.848	-0.583	**1**								
Ca^{2+}	0.691	-0.370	0.711	0.772	-0.701	**0.955***	**1**							
Mg^{2+}	-0.167	-0.924	**0.985***	**0.953***	-0.562	0.755	0.596	**1**						
K^{+}	**0.958***	0.107	0.252	0.356	-0.570	0.678	0.852	0.094	**1**					
Na^{+}	-0.519	-0.526	0.154	0.180	-0.476	-0.333	-0.280	0.164	-0.369	**1**				
Al^{3+}	0.805	-0.235	0.552	0.645	-0.771	0.832	**0.958***	0.406	0.941	-0.182	**1**			
S	0.515	-0.555	0.848	0.889	-0.727	**0.982***	**0.975***	0.759	0.718	-0.178	0.890	**1**		
CEC	0.228	-0.778	**0.970***	**0.984***	-0.731	0.929	0.861	0.920	0.477	0.014	0.731	**0.951***	**1**	
S/CEC	**0.969***	0.350	0.072	0.147	-0.230	0.611	0.740	-0.058	0.927	-0.685	0.787	0.584	0.309	**1**

** Significant at p<0.05*

Table 6. Pearson correlation matrix for linear relationships between selected soil parameters of Medji

Variables	pH_{H2O}	pH_{KCl}	OC	N	C/N	P	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	S	CEC	S/CEC
pH_{H2O}	**1**													
pH_{KCl}	0.154	**1**												
OC	0.335	-0.577	**1**											
N	0.261	-0.377	**0.919***	**1**										
C/N	-0.351	0.182	-0.833	**-0.975***	**1**									
P	0.406	0.101	-0.029	-0.353	0.389	**1**								
Ca^{2+}	0.140	0.010	0.734	0.784	-0.782	-0.002	**1**							
Mg^{2+}	0.232	0.149	0.625	0.619	-0.629	0.247	**0.961***	**1**						
K^{+}	0.329	-0.868	0.782	0.536	-0.385	0.176	0.188	0.115	**1**					
Na^{+}	0.252	-0.441	0.636	0.792	-0.794	-0.664	0.263	0.033	0.488	**1**				
Al^{3+}	-0.218	-0.869	0.320	0.270	-0.134	-0.472	-0.293	-0.496	0.640	0.618	**1**			
S	0.177	-0.002	0.748	0.775	-0.769	0.054	**0.998***	**0.971***	0.220	0.243	-0.302	**1**		
CEC	0.424	-0.252	**0.933***	**0.953***	**-0.940***	-0.077	0.876	0.786	0.527	0.614	0.037	**0.882***	**1**	
S/CEC	0.174	0.156	0.607	0.614	-0.623	0.210	**0.967***	**0.998***	0.081	0.026	-0.495	**0.973***	0.771	**1**

** Significant at $p<0.05$*

Table 7. Pearson correlation matrix for linear relationships between selected soil parameters Zavion

Variables	pH_{H2O}	pH_{KCl}	OC	N	C/N	P	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	S	CEC	S/CEC
pH_{H2O}	**1**													
pH_{KCl}	0.890	**1**												
OC	0.772	0.523	**1**											
N	0.782	0.469	**0.979***	**1**										
C/N	-0.436	-0.003	-0.479	-0.646	**1**									
P	0.877	0.661	0.561	0.667	-0.729	**1**								
Ca^{2+}	**0.957***	0.808	0.631	0.695	-0.583	**0.975***	**1**							
Mg^{2+}	**0.991***	0.881	0.695	0.726	-0.475	0.924	**0.985***	**1**						
K^{+}	0.672	0.275	0.885	**0.959***	-0.827	0.691	0.654	0.639	**1**					
Na^{+}	0.737	0.666	0.207	0.313	-0.511	0.912	0.887	0.821	0.336	**1**				
Al^{3+}	-0.229	-0.571	0.399	0.426	-0.409	-0.211	-0.292	-0.300	0.532	-0.558	**1**			
S	**0.964***	0.792	0.681	0.744	-0.612	**0.973***	**0.998***	**0.986***	0.704	0.857	-0.226	**1**		
CEC	0.890	0.640	**0.970***	**0.979***	-0.574	0.743	0.800	0.840	0.901	0.438	0.235	0.838	**1**	
S/CEC	0.905	0.824	0.463	0.530	-0.492	**0.954***	**0.978***	**0.954***	0.491	**0.954***	-0.472	**0.961***	0.661	**1**

** Significant at $p<0.05$*

Table 8. Land suitability evaluation of different studied soils for beans, potatoes and maize using simple limitation and parametric methods

Land, soil and climate characteristics	Medji									Bawa						Zavion								
	Beans			Potatoes			Maize			Beans		Potatoes		Maize		Beans			Potatoes			Maize		
	Summit	Midslope	Footslope	Summit	Midslope	Footslope	Summit	Midslope	Footslope	Summit	Footslope	Summit	Footslope	Summit	Footslope	Summit	Midslope	Footslope	Summit	Midslope	Footslope	Summit	Midslope	Footslope
Climate (c)																								
Precipitation during crop cycle (mm)	S3	S3	S3	S1-0	S1-0	S1-0	S3	S3	S3	S3	S3	S1-0	S1-0	S3	S3	S3	S3	S3	S1-0	S1-0	S1-0	S3	S3	S3
Mean temperature during crop cycle (ºC)	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S2	S2	S2
Topography (t)																								
Slope (%)	N2	S3	S1	N2	S3	S1	N2	S3	S1	N2	S2	N2	S2	S3	S2	N2	N2	N2	N1	N1	N1	N1	N1	N1
Wetness (w)																								
Flooding	S1-0	S1-0	N2	S1-0	S1-0	N2	S1-0	S1-0	N2	S1	N2	S1-0	N2	S1-0	N2	S1-0	S1-0	N2	S1-0	S1-0	N2	S1-0	S1-0	N2
Drainage	S1-0	S1-0	N2	S1-0	S1-0	N2	S1-0	S1-0	N2	S1	N2	S1-0	N2	S1-0	N2	S1-0	S1-0	N2	S1-0	S1-0	N2	S1-0	S1-0	N2
Physical soil characteristics (s)																								
Texture/Structure	S1-1	S1-1	S1-0	S1-0	S1-0	S1-1	S1-1	S1-1	S1-0	S1-0	S1-0	S1-1	S1-1	S1-0	S1-0	S1-1	S1-1	S1-1	/	S1-0	S1-0	S1-1	S1-1	S1-1
Coarse fragm (vol%)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Soil depth (cm)	S3	S1-0	S1-0	S3	S1-0	S1-0	S3	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-1	S1-0	S1-0	S1-0	S1-0	S1-0	S1-1	S1-0
Soil fertility characteristics (f)																								
Apparent CEC (cmol (+) kg-1 clay)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S1-0	S1-0	S2	S2	S2	S2	/	S1-1	S1-0	/	S1-1	S1-0	/	S1-1	S1-0
Base saturation (%)	S3	S2	S2	S2	S2	S2	S3	S3	S2	S1-1	S2	S1-1	S2	S1-1	S2	S3	S3	S1-1	S2	S2	S2	S3	S3	S2
pH_{H2O}	N2	S3	N2	S3	S2	S3	N2	S2	N2	S1-0	S1-0	S1-0	S1-1	S1-0	S1-1	S3	S3	S1-0	S2	S3	S1-1	S2	S3	S1-1
Org. carbon (%)	S1-1	S1-0	S1-0	S1-0	S1-0	S1-0	S1-1	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-1	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Salinity (n)																								
ESP (%)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0

4. CONCLUSION

The study soils are characterized by an AC or ABC horizon sequences. The development of each profile depends on the nature of the bedrock, its position in the landscape and the water table level. In the physicochemical view point, the pH is globally acidic, leading to high aluminium toxicity. The nutrient contents are low and the soils are highly desaturated. The growth of maize, beans and potatoes in the study area is limited by the high slope gradient, acidic pH, high rainfall and wetness in some footslopes. These limitations could respectively be solved by terracing of arable land, restoration of the cation balance through fertilization and liming, and by promoting crops cultivation at the end of the raining season or in the dry season if the soil humidity is sufficient, in order to increase the crop yields, stop rural migration and avoid conflict between breeders and farmers in the eastern slope of the Bambouto mountain.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAO. 2007. Land evaluation. Towards a revised framework. Land and water discussion paper number 6. FAO Technical paper, Rome; 2001.
2. Verdoodt A, Van Ranst E. Land Evaluation for Agricultural Production in the Tropics. A Large-Scale Land Suitability Classification for Rwanda. Laboratory of Soil Science, Ghent University. 2003; 175.
3. Smaling EMA, Nandwa SM, Janssen BH. Soil fertility in Africa is at stake. *In:* R.J. Buresh, P.A. Sanchez and F. Calhoom (eds.) Replenishing Soil Fertility in Africa. Soil Science Society of America Special Publ. 51. Madison, Wisconsin, USA. 1997; 47-61.
4. FAO (Food and Agriculture Organization). Soil fertility management in support of food security in Sub-Saharan Africa (SSA), Rome, Italy. 2001;55.
5. IFPRI. A 2020 vision for food, agriculture, and the environment. A synthesis of International Conference Jointly hosted by the International Food Policy Research Institute and the National Geographic Society Washington, D.C; 1995.
6. Martel YA, Mackenzie AF. Long-term effects of cultivation and land use on soil quality in Quebec. Canadian Journal of Soil Science. 1980;60:411-420.
7. Kang BT. Changes in soil chemical properties and crop performance with continuous cropping on Entisols in the humid tropics. *In:* K. Mulongoy and R. Merck (eds.). Proceedings of International Symposium. 4-6 November 1991, Laboratory of Soil Fertility and Biology, Katholieke Unversiteit, and International Institute of Tropical Agriculture (IITA). Leuven, Belgium; 1993.
8. Saikh H, Varadachari C, Ghosh K. Changes in carbon, nitrogen and phosphorus levels due to deforestation and cultivation. A case study in Simplipal National Park, India. Plant and Soil. 1998a; 198:137-145.
9. Saikh H, Varadachari C, Ghosh K. Effects of deforestation and cultivation on soil CEC and contents of exchangeable bases. A case study in Simplipal National Park, India. Plant Soil. 1998b;204:67-75.
10. Wakene N, Heluf G. Forms of phosphorus and status of available micronutrients under different land use systems of Alfisols in Bako area of Ethiopia. Ethiopian Journal of Natural Resources. 2003;5:17-37.
11. Rossiter DG. Lecture notes: Land evaluation. Cornell University, College of Agriculture and Life Sciences, Department of Soil, Crop and Atmospheric Sciences. 1994;29.
12. Smaling EMA. The soil nutrient balance: an indicator of sustainable agriculture in sub-Saharan Africa. The Fertilizer Society. Proceedings. 1993;340:1-18.
13. Vanlauwe B, Diels J, Sanginga N, Merckx R. Integrated Plant nutrient Management in Sub-saharan Africa: From Concept to Practice. CAB International Wallingford Oxon, UK. 2002; 352.
14. Jafarzadeh AA, Abbasi G. Qualitative land suitability evaluation for the growth of onion, potato, maize, and alfalfa on soils of the Khalat pushan research station. Biologia, Bratislava. 2006;61(Suppl. 19): 349-352.
15. Bationo A, Hartemink A, Lungu O, Naimi M, Okoth P, Smaling E, Thiombiano L. African soils: Their productivity and profitability of fertilizer use. Background paper prepared for the African Fertilizer Summit, June 9 – 13, Abuja, Nigeria; 2006.

16. Hartemink E. Land use change in the tropics and its effect on soil fertility. 19th World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010, Brisbane, Australia. Published on DVD; 2010.
17. Muya EM, Obanyi S, Ngutu M, Sijali IV, Okoti M, Maingi PM, Bulle H. The physical and chemical characteristics of soils of Northern Kenya Aridlands: Opportunity for sustainable agricultural production. Journal of Soil Science and Environmental Management. 2011;2(1):1-8.
18. Ngoufo R. Les monts Bambouto. Environnement et utilisation de l'espace. Thèse de doctorat 3ème cycle, Universté de Yaoundé, vol. I et II ; 1988. French.
19. Zali Vargahan B, Shahbazi F, Hajrasouli M. Quantitative and qualitative land suitability evaluation for maize cultivation in ghobadlou region, iran. ozean journal of applied sciences. 2011; 4(1):91-104.
20. Kilic S, Evrendilek F, Senol S, Gelik I. Developing a suitability index for land use and agricultural land covers: A case study in Turkey. Environ. Mon and Assess. 2005; 102:323-335.
21. Doubé M. Pedogenesis, Classification and charge properties of the bambouto soil sequence (West-Cameroon). Ph.D. These, State University of Ghent, Belgium; 1989.
22. Tematio P, Kengni L, Bitom D, Hodson M, Fopoussi JC, Leumbe O, et al. Soils and their distribution in Bambouto volcanic mountain, West-Cameroon Highland, Central Africa. Journal of African Earth Sciences. 2004;39:447-457.
23. Tematio P, Fritsch E, Hodson ME, Lucas Y, Bitom D, Bilong P. Mineral and Geochemical Characterization of a Leptic Aluandic Soil and a Thapto Aluandic-Ferralsol Developed on Trachytes in Mount Bambouto (Cameroon Volcanic Line). Geoderma. 2009;152(3-4):314-323.
24. Tematio P, Tsafack EI, Kengni L. Effects of tillage, fallow and burning on selected properties and fertility status of Andosols in the Mounts Bambouto, West Cameroon. Agricultural Sciences. 2011; 2(3):334-340.
25. Leumbe Leumbe O, Bitom D, Tematio P, Temgoua E, Lucas Y. Etude des sols ferrallitiques andiques sur trachyte en zone de montagne humide tropicale (monts Bambouto – Ouest Cameroun). Etude et Gestion des Sols, AFES. 2006;12(4):313-326. French.
26. Tsozué D, Bitom D, Lucas Y. Biogeochemistry of iron, aluminium and silicon in humid tropical mountainous soils (Bambouto Mountain, West Cameroon). The Open Geology Journal. 2009;3:70-81.
27. Tsozué D, Bitom D, Nghonda JP. Andosols of the eastern slope of the Bambouto Mountains (West Cameroon): General characteristics, impact human activities and environmental risks. Syllabus Review, Syllabus Review Sciences. 2011;2(2):57-68.
28. Tabi FO, Bitondo D, Yinda GS, Kengmegne SSA, Ngoucheme M. Effect of long term integrated soil fertility management by local farmers on nutrient status of a Typic Dystrandept under potato-based cropping system. International Research Journal of Agricultural Science and Soil Science. 2013;3(4):134-140.
29. Bitondo D, Tabi FO, Kengmegne SSA, Ngoucheme M, Mvondo Ze AD. Micronutrient Concentrations and Environmental Concerns in an Intensively Cultivated Typic Dystrandept in Mount Bambouto, Cameroon. Open Journal of Soil Science. 2013;3:283-288.
30. Tsopjio Jiomeneck PS, Tematio P, Wilson MA, Yemefack M. Andosolization of Soils on a Strombolian Cone at Mount Bambouto, Cameroon. Open Journal of Soil Science. 2011;1:97-105.
31. Morin S. Les dissymétries fondamentales des hautes terres de l'Ouest-Cameroun et leurs conséquences sur l'occupation humaine. Exemple des monts Bambouto. Revue <<homme et la montagne tropicale>> SEPANRIT, Bordeaux; 1988. French.
32. Ngoufo R. Milieux physique et contrainte d'aménagement agropastoral dans les monts Bambouto. Ministère du tourisme, Yaoundé; revue de géographie du Cameroun. 1989; 8(2). French.
33. Letouzey R. Notice de la carte phytogéographique du Cameroun au 1/500 000. Institut de la carte de végétation, Toulouse; 1985. French.
34. Baise D. Guide pour la description des sols. Institut National de la Recherche Agronomique (INRA), Paris ; 1995. French.
35. Walkey A, Black IA. Determination of organic matter in soil. Soil Science. 1934;37:549-556.

36. Kamprath EJ. Soil acidity and liming in soils of humid tropics. Ed. Nation. Acad. Sci., Washington; 1972.
37. Euroconsult. Agricultural compendium for rural development in the tropics and the subtropics, Elsevier Amsterdam. 1989;740.
38. Sys C, Van Ranst E, Debaveye J. Land evaluation. part 1: Principles in land evaluation and crop production calculation. General Administration for development cooperation. Agric. Publ. No 7, Brussels, Belgium; 1991a.
39. Sys C, Van Ranst E, Debaveye J. Land evaluation. part 11 : Methods in land evaluation. General Administration for development cooperation. Agric. Publ. No: **7**. Brussels, Belgium; 1991b.
40. Sys C, Van Ranst E, Debaveye J. Land evaluation. Part 111: Crop Requirements. International Training Center for Post Graduate Soil Scientists. Ghent University. Ghent, Belgium; 1993.
41. Temgoua E, Bitom D, Bilong P, Lucas Y, Pfeifer HR. Démantèlement des paysages cuirassés anciens en zone forestière tropicale d'Afrique Centrale, formation d'accumulations ferrugineuses actuelles au bas des versants. C. R. Géosciences. 2002;334:537-543. French.
42. Bitom D, Volkoff B, Beauvais A, Seyler F, Ndjigui PD. Rôle des héritages latéritiques et du niveau des nappes dans l'évolution des modelés et des sols en zone intertropicale forestière humide. C.R. Géoscience. 2004;336:1161-1170. French.
43. Tsozué D, Bitom D, Yongue-Fouateu R. Morphology, mineralogy and geochemistry of a lateritic soil sequence developed on micaschist in the Abong-Mbang region, South-East Cameroon. South African journal of Geology. 2012;115(1):103-116.
44. Asio VB, Carlito C, Cabunos Jr, Zueng-Sang Chen. Morphology, physiochemical characteristics, and fertility of soils from quaternary limestone in leyte, philippines. Soil Science. 2006;171(8):648-661.
45. Sharma SS, Totawat KL, Shyampura RL. Characterization and classification of salt affected soils of southern Rajasthan. Journal of the Indian Society of Soil Science. 2004;52:209-213.
46. Walia CS, Rao YS. Characteristics and classification of some soils of trans-Yamuna plain. Journal of the Indian Society of Soil Science. 1997;45(1):156-161.
47. Fisseha G, Gebrekidan H. Characterization and fertility status of the soils of Ayehu Research Substation, North western Highlands of Ethiopia. East African Journal of Sciences. 2007; 1(2):160-169.
48. Sehgal J. Pedology- Concepts and applications, Second Revised and Expanded Edition, Kalyani Publishers, New Delhi. 2009;516.
49. Babar k, Khattak RA, Hakeem A. Physico-chemical characteristics and fertility status of Gilgit soils. J. Agric. Res. 2004;42(3-4):305-312.
50. Singh H, Sharma KN, Arora BS. Influence of continuous fertilization to maze system on the changes in soil fertility. Fertilizer Research. 1995;40:7-19.
51. Kebeney SJ, Msanya BM, Ng'etich WK, Semoka JMR, Serrem CK. Pedological characterization of some typical soils of Busia County, Western Kenya: Soil morphology, physico-chemical properties, classification and fertility trends. International Journal of Plant & Soil Science. 2015;4(1):29-44.
52. Danladi A, Ray HH. A comparative study of soil fertility status under different crop cultivation in Gombe. African Journal of Agricultural research. 2014;9(28):2142-2145.
53. Beernaert F, Bitondo D. Land evaluation manual. Department of soil science, CUDs Dschang, Cameroon. 1993;398.

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