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Landscape related variability of physical and chemical soil characteristics in the Moist Savanna of Benin

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ABSTRACT
A detailed knowledge of the bio-physical environment in the Moist Savanna of Benin is crucial for regional land use planning and for the initiation and diffusion of improved nutrient management techniques. For this reason, the "SOTER Database Benin" (BENSOTER) has been developed. It comprises comprehensive information on soils, landform and climate. Based on topographic maps and field surveys, the landscape in the study area was divided into 7 terrain units (Mountains, Hills, Footslopes, High and Low peneplains, Plateaus and Floodplains) characterised by overall slope gradient and relief intensity. Depending on geology and soil parent material, these terrain units were subdivided at second level into 26 terrain components and 45 terrain sub-components. Soil transects with a total of 445 analysed profiles and topographic information were combined and extrapolated to provide information on spatial variability of soils within the terrain sub-components. For the management of soil and terrain data the SOTER (Soil and Terrain Digital Database) approach was used 26 profile sets, which consist usually of not more than two soil types, were morphologically distinguished in the field and correlated with the terrain sub-components. The profile sets differed especially in terms of their chemical characteristics such as exchangeable bases, CEC, pH, P_{Bray}, N_t, C_{org}. With respect to these six fertility parameters a fertility sequence was established: Clayey soils on gneiss, basalt and gabbro basements > sandy loam alluvial soils > sandy clay soils on gneiss and gabbro > sandy-clay-loam hydromorphic soils > loamy sandy colluvial soils > sandy-clay-loam well-drained soils on all basements > loamy sandy soils on granite. The levels of exchangeable bases seems to be sufficient for crop production in all soils, except in loamy sandy soils on Footslopes (on quartzite, granite, gneiss or rhyolite) and on High peneplains (on gneiss or mylonite) with continous cultivation. Overall, P seems to be the most limiting factor for crop production, followed by N on Arenosols and Planosols occuring in the terrain units Plateaus and Footslopes on gneiss or in the High peneplains on granite. The present investigation reveals a large heterogeneity of the soils in the Moist Savanna of Benin with respect to soil physical and chemical properties. The SOTER methodology constitutes a tool in the assessment and spatial quantification of soil variability, which may be useful in identifying soil fertility constraints and suitable management options for extension services and regional planning authorities.

Keywords: *Sub-humid Savanna, Benin, soil data base, soil fertility status, soil variability*

INTRODUCTION

The importance of soil as a basic resource for producing food, fibre and nowadays fuel has been recognised since the early days of agriculture. Good and appropriate advice to regional land use planning and agricultural extension services needs comprehensive knowledge of soil resources and soil fertility. The aim of the``SOTER-database Benin´´ (BENSOTER) (Igué et al., 1999) is to provide a detailed knowledge of the bio-physical environment in the Moist Savanna of Benin as a scientific basis for the decisions of regional planning authorities and for the identification of fertility constraints in relation to soil and landscape.

Soil information within the subhumid savanna of Benin is presently restricted to large scale maps at the reconnaissance level. Volkoff and Willaime (1965) published an overall soil map of Benin at the scale of 1:1,000,000, followed by soil maps at a scale of 1:200,000 which were interpreted by Roose (1976) with respect to soil and water conservation at the state level. However, those maps and the corresponding explanatory volumes lack information about the spatial variability of soils within the mapping units. With the exception of the soil map of West Savalou (Volkoff, 1966) and some pedological reports, more detailed soil surveys concentrate on the densely populated coastal region of Benin. In order to assess the variability of soil resources in the moist savanna region of Central Benin and to evaluate their fertility status, the present investigation has been carried out.

In the years 1990, many studies were made with SFB programme (Sonderforschungsbereich 308) in Central Benin on soil fertility, soil management, soil surveys, land evaluation and land use planning (Kühne 1993; Gaiser 1993; Ernst-Schaeben 1994; Akondé 1995;; Fritz 1996; Agbo, 1999. Igué, 2000; Weller 2002).

Some detail soil survey and mapping (scale 1/2000 to 1/25.000) were done at watershed and inland valley level with some projects (Igué and al., 2001; Yousouf and al., 2001; Maeir R. 2004; Junge, 2004; Bello M., 2006; Junge and Skowronek, 2007; Steup, 2008) and at village level (Igué and Dagbérou, 2007a, b; Azontondé, 2007a, b). These studies were used for small scale evaluation of soil suitability for agriculture production.

In the scope of the European Union water initiative for developing countries, the research programme RIVERTWIN (A Regional Model for Integrated Water Management in Twinned River Basins), SLISYS-Oueme was created to provide data about soils, climate and terrain conditions in the Oueme basin (Igué, 2005). On the base of terrain observations and morphological, geological and hydromorphy criteria, 14 terrain units were defined. These units were subdivided into 71 terrain components according to the petrography, slope gradient and relief intensity. From satellite images interpretation, 17 land use/cover classes were defined. The informations on soil, climate and land use were gathered to obtain LUSAC: Land Use-Soil Association-Climate unit) which are quasi-homogeneous with respect to land use, soil association and climate (Gaiser and al., 2006).

2. MATERIAL AND METHODS

2.1 Regional settings

The study area covers about 10 000 km² and concerns the southern part of the Precambrian crystalline rocks in Benin located immediately to the north of the continental terminal area. The study area belongs to the agroecological zone "sub-soudanian in transition" (Adam and Boko, 1983), and the climate is intermediate between the guinea-congolian and the soudano-guinean climate. Rainfall pattern is monomodal, the rainy season being from

April to October. The dry season lasts from November to mid March or April. Mean annual rainfall (1964-2010) amounted 1100-1200 mm, but more than 50% precipitates during four months (June to September, Igué et al., 2003). In geological terms the study area is located on the Precambrian crystalline rocks, usually known as the "basement complex". Petrographically, they are largely composed of acidic metamorphic rocks of the "Dahomeyen series" (gneiss, quartzite, migmatite). Included are granites and basic intrusive gabbro (Pougnet, 1957; Aicard, 1957).

2.2 Characterization of landscape / soil relationship

For the characterization of the relationship between landscape and soils, the SOTER (Soil and Terrain Digital Database) approach was applied (ISRIC, 1993). The concept is the identification of area of terrain (land units) with distinctive, often repetitive pattern of geomorphologic or geological elements together with a corresponding soil pattern (Shield and Coote, 1988; Brabant, 1992). The mapping units are stored in two different sections: a) the geometry in a GIS; and b) attribute informations (i.e. slope) in a separate database on three main levels (Igué and al., 2003). At the first level Terrain Unit (TU) characterized by elevation, major landform and general lithology. A terrain unit has one or more terrain components. Terrain components (TC) reflect slope, surface form, depth to groundwater (Igué and al., 2003). Soil components (SC) are described by some general data such as position and proportion in the TC, surface properties etc. and by a profile set (Weller and Stahr, 1995; Igué and al., 2003).

In the first step, the study area was subdivided into seven TU according to overall slope gradient and relief intensity. These terrain units were further subdivided into TC and Terrain Sub-Components (TsC). Finally, 26 terrain components and 45 terrain sub-components were identified (Igué, 2000; Igué and al., 2003). Each terrain sub-component comprises one or more soil components. With regard to the undetectable heterogeneity of soils and the problem of the selection of representative reference profiles, a soil component is described by a set of profile descriptions (see Section 2.3).

2.3 Field work

The survey area was investigated from 1997 to 1999 with more than 100 transects that covered a total length of 797 km. Over 1050 field observations by augers, drillings and profiles were made in the Terrain Units (TU) and Terrain Components (TC) to provide information of occurring soil components and their spatial distribution (Igué and al., 2003). Thus, an extensive inventory of characteristics and spatial distribution of soil and terrain types was obtained. Soils were classified according to the revised legend of the FAO soil map of the world (ISRIC, 1997) and then grouped into 26 profile sets, which can be distinguished in the field by parameters like texture, colour, clay translocation, stoniness, hydromorphic features and geological substrate. Mapping of terrain units and terrain sub-components was carried out using detailed topographic and geological maps at the scale 1:50.000 (Igué and al., 2003). Each profile set was linked to exactly one soil component. The soil components within the terrain sub-components were not mapable at the selected scale, due to the large spatial variability.

2.4 Laboratory method

More than 1000 soil horizon samples were taken. The soil samples were air-dried, ground, sieved to pass a 2 mm sieve and analysed at Centre National d'Agro-Pedologie (CENAP) using methods described by Tranh, (1976). Analyses included:

Texture (5 fractions by Robison method),
pH (H_2O) by electro-metric measurement in H_2O suspension with a soil/water fraction of 1:2.5),
Organic carbon: Oxidation with potassium dichromate and titration with iron ammonium sulphate
Total nitrogen: following KJELDAHL the soil sample were dissolved in concentrated sulphuric acid. After alkalinization the ammonia was distilled, catched with boronic acid and titrated with 0.05 mol/l HCl.
Exchangeable bases: extraction of bases with 30 m^3 of 1 mol^+ ammonium acetate solution at pH 7 and determination of Ca, Mg, K, Na with spectrophotometer
Cation exchange capacity (CEC): after extraction of the bases the sample were washed with ethanol and exchanged with 10 % KCL solution at pH 2.5. The exchangeable ammonia was determined by distillation
Available phosphorus: extraction of the readily acid-soluble forms of P in 0.03 mol/l HCl, and colorimetric determination with the blue ammonium molybdate method (Bray I method)

2.5 Data base development

The SOTER methodology provided a framework to store the identified terrain units and related soil data in a relational database, which includes observed and analytical attribute data with respect to terrain units, terrain components, soil components and profile sets as well as GIS-based terrain data. In the SOTER approach, the soil and terrain digital database is linked with GIS. The resultant system forms an important tool for storing, updating and manipulating the spatial and attributes data of a wide of climate, terrain and soil. The actual BENSOTER database comprises 445 soil profiles, 65 of which were extracted from external sources (Igué et al, 1999, Igué and al., 2003). Mean chemical characteristics of the topsoil (<30 cm depth) and subsoil (>30 cm depth) of each soil profile were calculated as the weighted average of the horizons over the respective depth. The mean characteristics of the profile sets are the average over the profiles within each profile set.

3. RESULTS AND DISCUSSION

3.1 Soil / landscape patterns

The landscape in the moist savanna zone of Benin is characterised by flat to undulating relief with large peneplains and some cuesta-shaped mountains or inselbergs as hardly weatherable remnants of the underlying basement (Figure 1). In the study area seven landscape units can be distinguished by the overall slope gradient and relief intensity: mountains, hills, plateaus, footslopes, high and low peneplains and floodplains (Igué et al., 1999) (Table 1). The peneplains are the dominant landforms in the area, whereas plateaus, mountains, hills footslopes and floodplains occur as inclusions (Figures 2 and 3). As indicated by Fritz (1996), the soil distribution in the study area is more influenced by parent material than relief (Igué and al., 2003; Igué and al., 2004). Therefore, the terrain units were further subdivided at a second level (Table 2) according to the kind of parent material on which the soils developed (gneiss, migmatite, granite, basalt, gabbro, quartzite or volcano-sedimentary intrusive mylonite and rhyolite) (Pougnet, 1957; OBEMINES, 1989, Igué and al., 2003;).
Most soils of the High peneplains on gneiss, migmatite, mylonite, rhyolite and sandstone are Ferric Luvisols with a CEC of more than 24 meq/kg of clay (Table 2). Chromic Acrisols, Ferric Alisols and Ferric Lixisols are also found associated sometimes with Haplic Arenosols on the transect. The B horizons are rich in Fe-Mn concretions, quartz gravels and stone fragments which are sometimes cemented into "ironstone".

Removal of surface materials due to erosion leads to skeletic or petroferric phases, which encourage water stagnation (Stagnic Luvisols) in footslope positions.

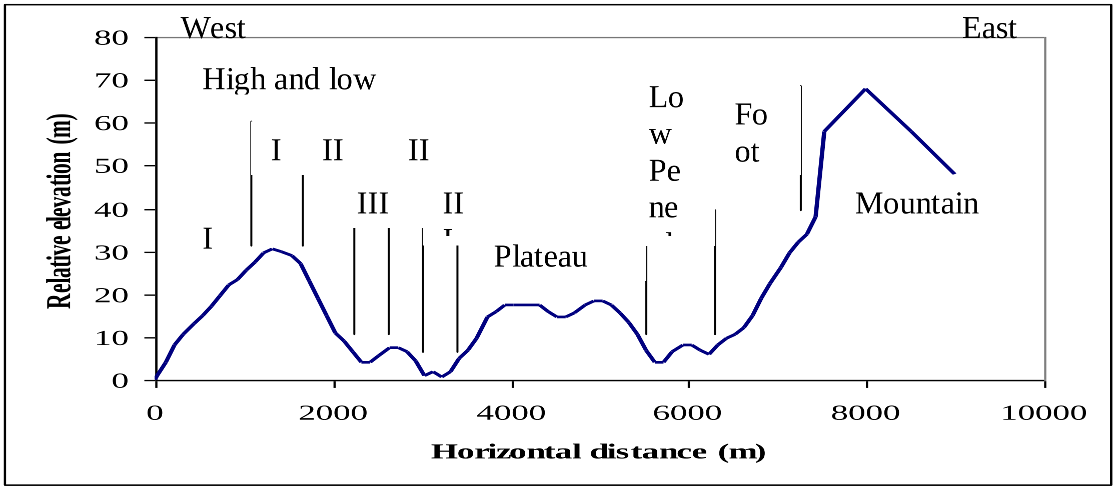

Figure 1: Representative transect of the geomorphic units “High and Low Peneplain” and “Mountain” on gneiss basement at Savalou (I: crest, II: slope, III: valley)

Table 1: Characteristics of the terrain units identified in moist savannah of central Benin

Key	*Terrain units*	Slope class	Relief intensity
T	Mountains and major scarps	> 30%	> 400m/km
S	Hills and minor scarps	8 to 30%	> 200m/km
P	Plateaus	2 to 3%	< 40m/km
F	Footslopes	4 to 8%	> 40m/km
L	High peneplain	3 to 4%	30 to 40m/km
V	Low peneplain	< 3%	< 5m/km
Va	Floodplains	<1%	< 2m/km

The evolution of this phenomena permits formation of Plinthosols (Dubroeucq, 1967; Igué, 2000; Junge and Skowronek, 2007). When the soils are formed from granitic and quartzitic basement, the major soils are Haplic Arenosols associated with Eutric Regosols. In the Low peneplains the major soil units are Mollic Gleysols, Eutric Vertisols, Eutric Cambisols and Mollic or Stagnic Solonetz. These soils, having developed on basic rocks, have a high clay content and CEC, and they often contain concretions of iron oxides. Organic matter content is high and the topsoil with organic matter accumulation reaches down to a depth of 0.5-0.6 m. In Floodplains, Mollic Fluvisols occupy terraces of the Mono River and some valleys.

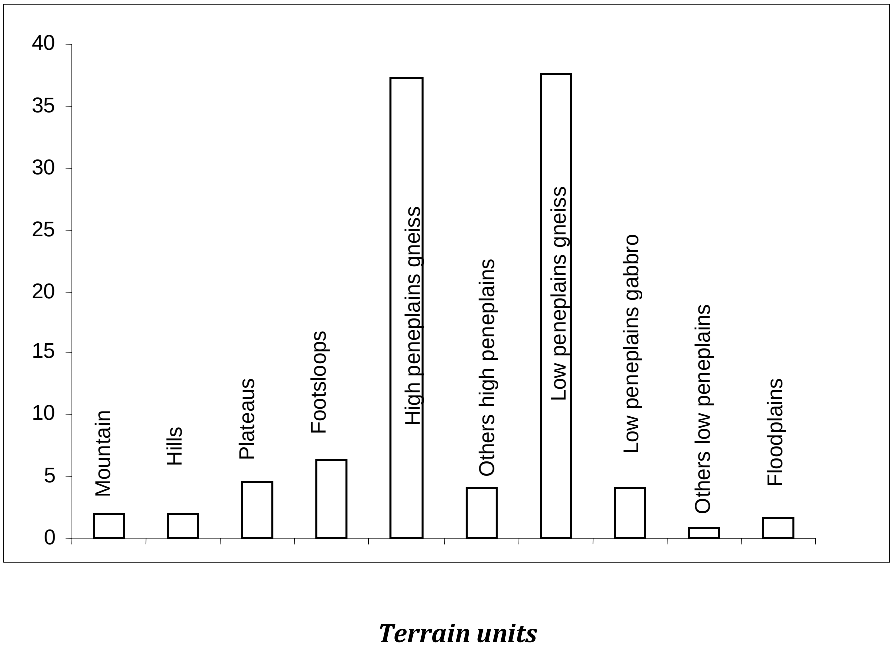

Figure 2: Coverage (%) of the Terrain units in the study area.

Table 2: Profile sets and their relation to terrain units and terrain components in the study area

SOTER Terrain units	Terrain components [1]	Major soil types
Mountains	Tgn, Tg, Tq	Leptosols, Luvisols, Alisols, Cambisols
Hills	Sgn, Sg,Sb, Sr	Leptosols, Luvisols, Cambisols
Footslopes	Fb, Fg, Fq, Fgn, Fr1, Fr2, Fcr	Cambisols, Arenosols, Luvisols, Leptosols, Acrisols, Regosols
Plateaus	Pgn, Pg	Alisols, Luvisols, Regosols, Arenosols, Leptosols
High peneplains	Lgn Lg, Lg, Lm, Ls	Luvisols, Arenosols, Plinthosols, Acrisols, Alisols, Regosols, Lixisols, Cambisols, Solonetz
Low peneplains	Vgn, Vga, Vm, Vc	Gleysols, Vertisols, Cambisols, Solonetz, Arenosols
Floodplains	Va	Fluvisols

[1] Symbols are a combination of terrain unit key (Table 1) and soil parent material (ga = gabbro, gn = gneiss, g = granite, q = quartzite, m = myolite, r = rhyolite, rb = rhyolite with basalt intrusions, s = sandstone, b = basalt, c = colluvial sediments, cr = cretaceous sediments)

3.2 Spatial variability of soil properties

Soil physical characteristics

The potential rooting depth is an expert assessment of the depth to which root growth is unrestricted by physical or chemical limitations (FAO, 1990) and it is an important criterion for land evaluation. The profile sets presented in Table 3 show that most soils were classified as moderately deep (16 profile sets) with limitations to root growth through bedrock, hydromorphy or high content of coarse fragments. A deep well drained soil presents a potential rooting depth until 150 cm for most plants, although experience has shown that most crops will produce excellent yields with an effective root zone depth of 90 cm (Sys, 1976). Only six profile sets (3, 5, 7, 8, 9 and 10) are very deep or deep without limitations to root growth. Some profile sets to which belong Plinthosols, Regosols, Planosols and Leptosols were classified as shallow. They occur in the terrain units Mountains, Footslopes (on gneiss or quartzite), and in the High peneplains (on gneiss, myolite, granite and sandstone) (Table 2).

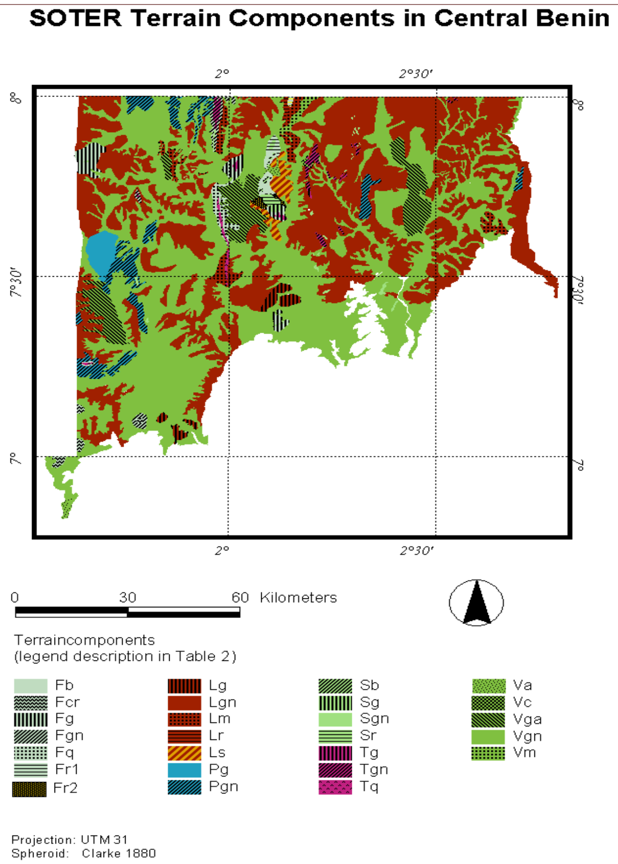

Figure 3 : Spatial distribution of terrain components in the moist savannah of Central Benin (Compare table 2)

Table 3: Definition and proportion of individual soil profile sets

Profile set id 2	Description	Number of Profiles	% of all profiles[2]	Texture	Potential rooting depth (cm)
1 BJIG-LVfgn	Yellowish-brown gravelly Luvisols on gneiss or migmatite (LVf)[1]	43	9.6	LS/SCL	50 – 100
2 BJIG-ALfgn	Red gravelly Alisols and Lixisols on basement (Alf/ LXf)	40	9	SL/SCL	50 – 100
3 BJIG-ACh	Red Luvisols, Alisols, Acrisols without gravels LVx/Alu/Ach	23	5.2	SL/SCL	100 – 150
4 BJIG-LVfo	Red gravelly Luvisols on other basements (LVf; ALf)	16	3.6	SL/SCL	50 – 150
5 BJIG-LVcr	Luvisols and Lixisols on Cretaceous sediment (LVx/LXh)	4	0.9	LS/SCL	100 – 150
6 BJIG-LVg	Luvisols with gleyic or stagnic properties on basement (LVj,g)	13	2.9	SL/SCL	50 – 100
7 BJIG-ARgn	Arenosols on gneiss or mgn basement (ARb,h)	8	1.8	LS/LS	> 150
8 BJIG-ARgr	Yellowish-brown sandy soils on granite (ARb,h)	5	1.1	LS/LS	> 150
9 BJIG-ARco	Sandy soils from colluvium (ARh)	6	1.3	LS/LS	> 150
10 BJIG-ARgg	Sandy soils with gleyic properties on basement (ARg)	10	2.2	LS/LS	100 – 150
11 BJIG-PT	Soils with carapace on basement (Pte)	15	3.4	SL/SCL	20 – 50
12 BJIG-RG	Sandy soils with high gravel content and stones (RGe)	36	8.1	LS/LS	20 – 50
13 BJIG-VRgn	Vertisols, black clay soils on gneiss or mgn rich in Fe-Mg (VRe)	18	4	CL/C	50 – 100
14 BJIG-CMgn	Cambisols on gneiss or migmatite (CMv,e)	29	6.5	SCL/SC	50 – 100
15 BJIG-CMggn	Gleyic Cambisols on gneiss or mgn (CMg)	16	3.6	SL/SCL	50 – 100
16 BJIG-PHgn	Phaeozems, soils with high carbon content (PHh,g)	5	1.1	SL/SCL	50 – 100
17 BJIG-PLgn	Planosols, clays with albic horizon on gneiss (PLe)	3	0.7	L/SC	20 – 50
18 BJIG-SN	Solonetz, soils with high sodium, ESP more 15%	22	4.9	SL/SCL	50 – 100
19 BJIG-GL	Gleysols on basement (GLm,e)	67	15	SL/SCL	50 – 100
20 BJIG-CMGso	Cambisols and Gleysols with sodium, ESP 6 to 14	29	6.5	SCL/SC	50 – 100
21 BJIG-VRga	Vertisols on gabbro (VRe)	7	1.6	CL/C	50 – 100
22 BJIG-CMga	Cambisols on gabbro (CMe,v)	3	0.7	SL/SCL	50 – 100
23 BJIG-CMba	Cambisols on basalt (CMe,v)	7	1.6	L/C	50 – 100
24 BJIG-CMgba	Gleyic Cambisols on basalt (CMg)	2	0.5	L/C	50 – 100
25 BJIG-FL	Loamy-clayey Fluvisols (FLm,e)	13	2.9	SL/SL	50 – 100
26 BJIG-LP	Leptosols on basement (LPe)	5	1.3	SL	20 – 50

[1] Acronyms according to ISRIC (1997). 2 Code of profile set

Table 4: Mean pH, organic carbon (Corg), total nitrogen (Nt), available P (Pa) and exchangeable sodium percentage (ESP) of the profile sets defined in Table 3 (SD = standard deviation)

N°	Texture	N	≤30 cm depth										≥30 cm depth									
			pH (H_2O)	SD	Corg (g kg^{-1})	SD	Nt (g kg^{-1})	SD	ESP (%)	SD	Pa (mg kg^{-1})	SD	pH (H_2O)	SD	Corg (g kg^{-1})	SD	Nt (g kg^{-1})	SD	ESP (%)	SD	Pa (mg kg^{-1})	SD
1	LS/SCL	43	6.5	0.4	7.2	3.1	0.54	0.24	2.1	3.1	4.9	4.7	6.4	0.4	2.0	1.8	0.25	0.49	2.2	3.9	0.9	1.2
2	SL/SCL	40	6.5	0.3	8.6	3.6	0.65	0.20	2.0	1.5	4.9	5.9	6.2	0.4	1.1	0.8	0.09	0.07	1.7	1.4	1.5	5.0
3	SL/SCL	23	6.8	0.5	7.9	2.7	0.64	0.23	2.2	2.3	11.6	17.4	6.4	0.7	1.2	1.0	0.11	0.08	2.1	1.8	2.1	3.7
4	SL/SCL	15	6.3	0.5	8.2	2.6	0.68	0.17	3.1	4.3	5.9	3.9	6.3	0.5	1.4	1.2	0.13	0.12	2.5	3.1	0.9	0.9
5	LS/SCL	4	6.3	0.5	7.2	2.6	0.61	0.14	2.9	1.6	3.4	0.0	6.0	0.8	1.2	0.5	0.11	0.04	2.9	2.0	0.5	0.0
6	SL/SCL	15	6.6	0.5	8.1	1.9	0.67	0.16	3.8	8.2	6.5	5.2	6.5	0.5	1.7	2.5	0.17	0.21	2.3	1.9	1.2	1.1
7	LS/LS	9	6.8	0.5	5.8	1.1	0.48	0.08	3.2	3.1	10.5	8.4	6.8	0.4	0.6	0.3	0.07	0.07	4.8	4.9	0.8	0.6
8	LS/LS	6	6.4	0.3	5.1	1.5	0.46	0.11	3.3	4.4	4.6	1.6	6.3	0.2	0.5	0.3	0.05	0.02	5.4	9.7	0.5	0.1
9	LS/LS	5	6.7	0.6	11.0	5.6	0.88	0.35	1.7	1.1	33.7	30.8	6.5	0.7	0.4	0.3	0.04	0.03	5.3	1.4	0.8	0.3
10	LS/LS	9	6.3	0.4	5.8	2.1	0.49	0.15	3.0	3.4	3.8	1.3	6.3	0.6	0.5	0.3	0.04	0.02	4.7	5.8	0.7	0.2
11	SL/SCL	16	6.4	0.4	7.1	2.6	0.55	0.17	3.0	2.4	12.5	12.4	6.2	0.5	2.3	3.4	0.21	0.26	4.2	5.7	2.6	3.3
12	LS/LS	37	6.5	0.4	6.1	2.3	0.52	0.19	2.5	3.2	4.2	3.9	6.5	0.4	1.4	1.3	0.15	0.15	4.5	5.5	0.6	0.3
13	CL/C	17	6.6	0.4	16.2	3.4	1.20	0.33	2.1	2.3	16.0	21.6	7.0	0.6	4.6	2.4	0.42	0.23	5.5	8.5	2.6	1.7
14	SCL/SC	30	6.5	0.3	11.1	3.3	0.83	0.20	2.4	2.1	6.9	7.7	6.9	0.5	3.9	3.5	0.27	0.18	3.8	3.3	0.8	0.5
15	SL/SCL	16	6.5	0.3	8.8	2.1	0.69	0.14	2.1	1.5	4.8	4.7	6.6	0.2	2.1	1.1	0.20	0.14	3.2	2.2	1.1	1.0
16	SL/SCL	5	6.6	0.3	16.3	11.2	1.30	0.83	2.4	2.2	30.6	44.6	7.1	0.7	7.3	7.2	0.62	0.59	6.3	4.2	17.0	28.3
17	L/SC	2	6.0	0.0	9.7	0.7	0.49	0.08	1.9	0.2	3.6	0.0	7.2	0.2	2.0	1.2	0.15	0.07	2.1	0.0	0.5	0.0
18	SL/SCL	24	6.4	0.5	8.4	2.9	0.66	0.22	9.0	5.6	1.7	1.0	7.7	0.8	1.8	1.7	0.16	0.15	31.7	14.9	0.7	0.5
19	SL/SCL	66	6.3	0.4	8.2	3.0	0.72	0.62	2.3	2.9	5.3	9.9	6.4	0.6	1.7	1.4	0.16	0.12	3.9	5.3	0.9	1.3
20	SCL/SC	26	6.5	0.3	8.7	4.3	0.68	0.28	3.4	2.6	13.8	34.2	7.4	0.8	1.6	1.4	0.14	0.10	13.5	8.2	5.9	17
21	CL/C	8	6.5	0.2	19.7	8.8	1.31	0.53	1.8	1.7	19.4	17.8	7.2	0.2	3.6	1.7	0.26	0.11	3.2	3.3	4.2	4.7
22	SL/SCL	2	6.4	0.0	9.9	2.8	0.86	0.06	3.0	1.8	8.0	0.0	6.6	0.1	3.8	0.9	0.32	0.10	1.0	0.4	1.0	0.0
23	L/C	6	6.7	0.3	17.6	6.7	1.27	0.45	0.1	0.2	12.7	1.8	6.6	0.4	4.7	2.8	0.42	0.21	0.8	0.9	0.4	0.0
24	L/C	2	6.4	0.0	15.2	3.2	1.19	0.27	0.0	0.0	13.2	12.2	6.5	0.0	3.1	0.4	0.26	0.05	0.8	0.0	0.8	0.0
25	SL/SL	12	6.0	0.4	13.2	6.3	0.91	0.27	2.0	1.7	13.0	14.5	6.4	0.4	2.2	3.1	0.14	0.15	5.9	7.4	2.8	5.0
26	SL	6	6.4	1.1	24.8	14.9	1.86	1.19	1.4	1.1	27.6	40.1	6.8	0.5	15.5	9.5	1.17	0.63	2.3	2.2	27.0	35.3

[a]for profile set numbers refer to Table 3

Table 5:Mean cation exchange capacity (CEC), base saturation (BS) and concentrations of exchangeable cations of the profile sets (SD = standard deviation)

N°	Texture	N	≤30 cm depth												≥30 cm depth											
			Ca	SD	Mg	SD	K	SD	Na	SD	CEC	SD	BS	SD	Ca	SD	Mg	SD	K	SD	Na	SD	CEC	SD	BS	SD
					(cmol kg^{-1})						(%)								(cmol kg^{-1})						(%)	
1	LS/SCL	43	3.7	2.5	1.0	0.9	0.37	0.44	0.1	0.2	7.2	6.0	80	25	3.7	1.6	2.0	1.5	0.27	0.15	0.2	0.4	9.3	3.4	68	15
2	SL/SCL	40	3.0	1.4	1.2	0.7	0.35	0.34	0.1	0.0	7.4	2.6	65	22	2.4	1.2	1.5	1.2	0.32	0.32	0.1	0.1	10.2	3.7	45	16
3	SL/SCL	23	4.1	3.2	1.0	0.6	0.35	0.19	0.1	0.1	7.3	3.2	73	25	3.2	3.5	1.3	1.4	0.33	0.21	0.1	0.1	9.4	4.8	53	20
4	SL/SCL	15	3.3	1.9	0.7	0.4	0.36	0.43	0.1	0.1	6.2	2.3	72	22	3.3	2.0	1.4	1.2	0.40	0.49	0.2	0.2	9.3	4.0	58	17
5	LS/SCL	4	3.5	2.2	0.9	0.2	0.27	0.09	0.2	0.1	5.8	2.2	82	14	2.7	1.4	0.6	0.2	0.23	0.14	0.1	0.1	7.1	2.2	53	16
6	SL/SCL	15	3.7	1.3	1.3	0.5	0.24	0.14	0.3	0.9	6.8	2.2	81	21	4.3	2.2	1.8	0.9	0.22	0.10	0.2	0.1	9.9	4.4	68	14
7	LS/LS	9	2.9	1.0	0.8	0.3	0.24	0.09	0.1	0.1	6.3	2.3	72	21	1.7	0.9	0.7	0.5	0.21	0.09	0.1	0.1	4.6	1.9	62	23
8	LS/LS	6	1.8	0.8	0.4	0.1	0.26	0.09	0.1	0.1	4.5	1.1	63	15	0.7	0.3	0.2	0.0	0.15	0.06	0.1	0.1	2.8	1.0	48	22
9	LS/LS	5	4.1	2.6	1.0	0.6	0.32	0.11	0.1	0.0	6.4	2.0	80	29	0.6	0.1	0.3	0.1	0.17	0.06	0.1	0.0	2.7	0.6	50	16
10	LS/LS	9	1.9	1.1	0.5	0.2	0.17	0.07	0.1	0.1	4.5	1.3	60	21	0.8	0.3	0.2	0.1	0.11	0.06	0.1	0.1	2.7	0.9	50	19
11	SL/SCL	16	2.6	0.8	0.9	0.3	0.30	0.15	0.1	0.1	5.6	1.8	77	26	3.1	1.4	1.9	1.2	0.37	0.39	0.4	0.9	10.0	4.3	65	24
12	LS/LS	37	2.6	1.1	0.7	0.3	0.19	0.09	0.1	0.1	4.8	1.5	77	23	1.6	0.9	0.5	0.4	0.18	0.14	0.1	0.1	4.3	1.8	62	19
13	CL/C	17	15.3	4.3	6.8	2.6	0.77	1.23	0.6	0.7	26.1	6.8	92	19	18.4	4.9	8.3	3.2	0.44	0.72	1.3	2.0	28.1	6.5	95	5
14	SCL/SC	30	9.6	4.1	3.7	2.3	0.34	0.20	0.3	0.2	15.3	5.7	90	13	13.2	5.2	6.0	2.6	0.36	0.23	0.6	0.5	21.4	6.5	91	12
15	SL/SCL	16	5.8	2.3	2.1	1.3	0.35	0.22	0.2	0.1	10.6	3.9	81	14	9.8	4.3	5.2	3.1	0.32	0.14	0.5	0.4	18.3	5.2	79	17
16	SL/SCL	5	6.1	3.3	2.3	0.7	0.71	0.69	0.2	0.2	10.7	3.6	84	16	9.7	6.9	3.5	3.0	0.40	0.23	1.0	0.8	13.4	4.1	85	18
17	L/SC	2	4.8	0.0	1.2	0.0	0.87	0.62	0.1	0.0	8.5	0.9	93	13	12.7	1.4	6.8	2.0	0.62	0.32	0.4	0.1	20.1	5.5	97	3
18	SL/SCL	24	4.4	3.7	2.4	1.8	0.22	0.10	1.2	1.1	10.5	5.4	74	19	7.8	5.0	6.0	2.5	0.29	0.12	6.1	2.6	20.8	8.3	91	13
19	SL/SCL	66	3.7	2.5	1.5	1.3	0.28	0.32	0.1	0.1	8.3	3.9	68	19	6.0	3.8	3.6	2.1	0.31	0.40	0.5	0.8	14.5	5.7	69	21
20	SCL/SC	26	4.6	2.8	2.2	2.0	0.30	0.22	0.5	0.6	11.2	6.8	69	20	9.4	5.5	5.5	3.3	0.30	0.14	2.8	2.2	19.5	5.8	84	15
21	CL/C	8	18.1	5.9	8.7	4.8	0.42	0.25	0.5	0.5	30.2	8.5	94	31	19.3	6.5	10.1	5.9	0.25	0.11	0.9	1.0	29.9	9.1	91	16
22	SL/SCL	2	8.1	0.2	4.1	1.7	0.32	0.06	0.4	0.2	14.8	1.4	88	7	9.3	2.2	5.2	0.1	0.30	0.04	0.2	0.0	18.1	2.3	80	5
23	L/C	6	10.9	7.1	2.9	0.8	0.96	1.35	0.0	0.0	18.4	5.6	79	28	9.8	3.5	3.9	1.5	0.36	0.21	0.1	0.2	21.2	6.2	69	12
24	L/C	2	10.1	1.9	3.1	0.0	0.42	0.03	0.0	0.0	16.9	0.1	82	12	8.9	1.1	3.3	0.3	0.27	0.05	0.1	0.0	17.1	0.3	74	8
25	SL/SL	12	5.1	2.8	1.9	0.9	0.34	0.15	0.2	0.2	11.4	4.6	67	25	3.5	1.5	2.1	1.5	0.22	0.14	0.5	1.0	9.2	3.3	68	18
26	SL	6	11.0	7.0	2.9	1.9	0.66	0.52	0.1	0.1	12.7	4.9	99	30	5.7	1.0	2.0	1.6	0.47	0.21	0.1	0.1	9.5	2.3	88	7

[a]for profile set numbers refer to Table 2

Texture is considered as one of the most important characteristics with regard to physical soil qualities. It influences such important soil properties as soil water availability, infiltration rate, drainage, tillage conditions and partly the capacity to retain nutrients (Igué, 2000). The effects of texture on those properties may be modified by structure, nature of the clay minerals, organic matter content and lime content. Table 3 shows that 60% of the soils observed in the study area are sandy loam in the topsoil and sandy-clay-loam (SL/SCL) in the subsoil, 14% are purely loamy sand (LS/LS) and 14% are sandy clay loam or loam on sandy clay (L-SCL/SC). A few numbers of soils are clay loam or loam over clay (CL-L/C, profile sets 13, 17, 21, 23 and 24 Table 3). The sandy-clay-loam soils can be divided into hydromorphic and well-drained groups. Hydromorphic soils (e.g. profile sets 19 and 20) occur almost exculsively on footslopes (with basaltic influence) or in the low peneplains (on gneiss, gabbro and myolite).

Generally in tropical soils, the silt fraction is low. However, a considerable proportion of silt has been being noticed in the topsoil of clay soils (23-42%) in the study area. With the exception of profile sets 8, 9 and 25, all profile sets show a clay increase with depth. The increase ranges from 9 to 20% for sandy clay loam soils, 7 to 28% for clay soils and up to 3% for loamy sandy soils.

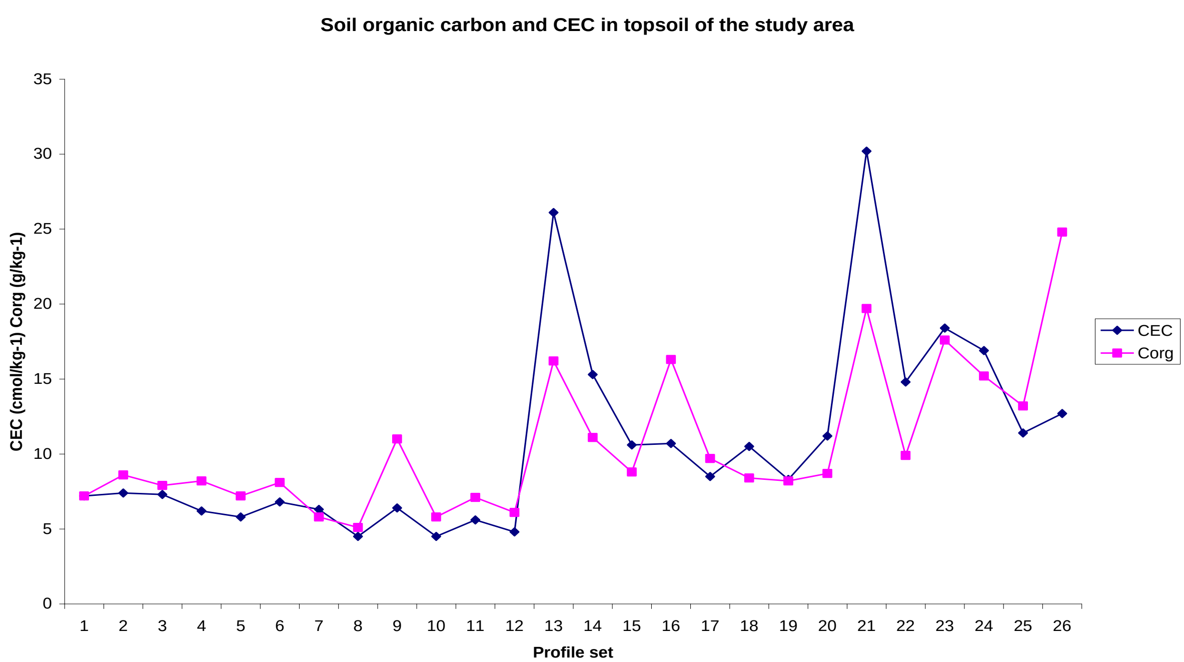

Figure 4: Soil organic carbon and CEC in topsoil of the study area

Soil chemistry

Soil acidity has a direct influence on chemical and biological soil parameters. Table 4 shows that pH (H_2O) values are usually between 6 and 7. The soils of Central Benin can be classified in three categories of acidity in the topsoil and subsoil. All profile sets are neutral or weakly alcaline in the topsoil. In the subsoil, pH values between 6 and 7 are most common, although some profile sets (18 and 20) show a pH of 7.4-7.7. These profile sets correspond to Gleysols, Solonetz and Cambisols with sodic phase. Some soil profiles within this group show a subsoil pH as high as 9. Some individual soils with leached horizons and signs of degradation due to frequent agricultural use with no inputs have low pH (5-6). In most soils the pH decreases with depth (Table 4). High topsoil pH may be due to base renewal through the plant-soil biocycling or dust input through the Hamattan (Ter Kuile, 1983; Igue, 1992). Elevated subsoil pH may indicate a) base-rich substrate such as weathered migmatite, alkaline gneiss, basalt or alluvial material, b) accumulation of bases caused by stagnating water or groundwater influence. Therefore, they occur most frequently in the terrain units Low peneplains and Floodplains.

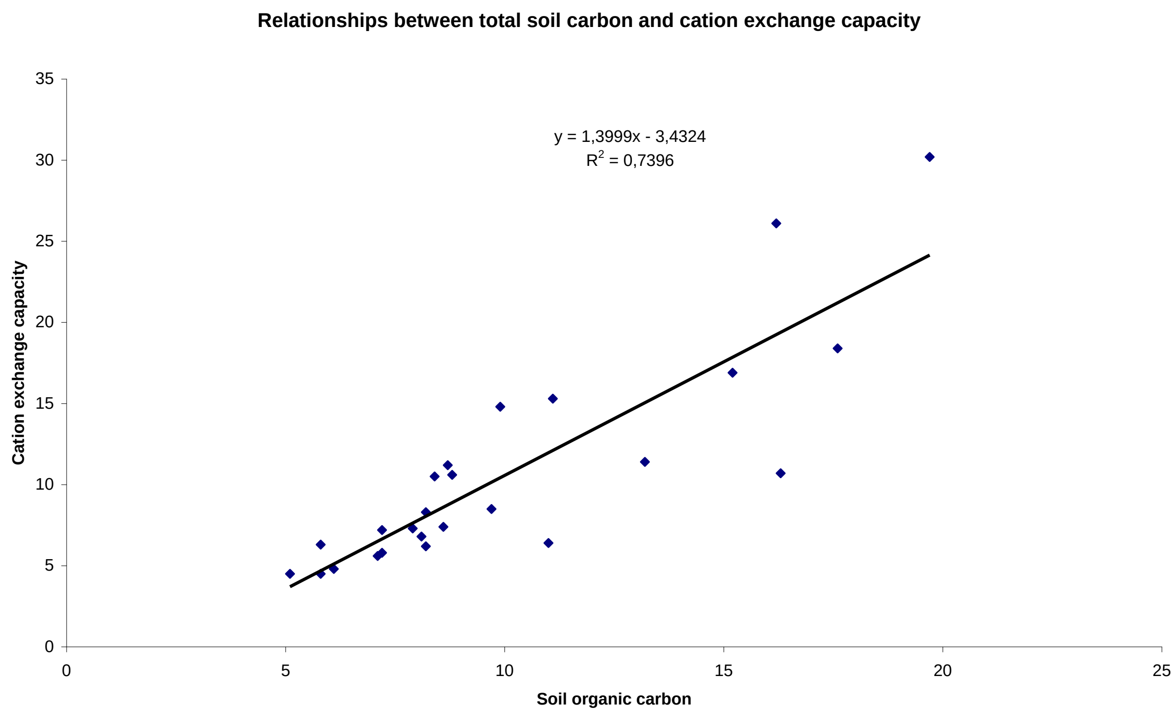

Figure 5: Relationship between soil organic carbon and cation exchange capacity

Alkalinity of soils can be indicated by the exchangeable sodium percentage (ESP %). In the FAO guidelines it characterises the natric horizon (FAO, 1998). Soils with high ESP (15% and more) are called sodic soils or Solonetz. Three classes are defined (Acres et al, 1993 modified), as follows: Sodic (ESP > 15%), Slightly sodic (ESP 6-15%) and Non-sodic (ESP < 6). Sodic soils account for 5% (profile set 18) and slightly sodic soils for 6.5% of the studied soil profiles (some Gleysols and Cambisols). Table 4 shows that profile set 18 has a mean ESP of 9% in the topsoil and 31.7% in the subsoil. Alkalinity is also high in the subsoil of the profile set 20 (ESP = 13.5%). Volkoff (1966) and Levêque (1979) attribute this alkalinity to higher Na concentrations in the substrate.

In addition to soil reaction, soil organic carbon and nitrogen content, nutrient availability is characterised by cation exchange capacity and exchangeable bases (calcium, magnesium, potassium and sodium). Average CECs (cmol kg^{-1}) range from 4.1-6.5 (loamy sandy soils) to 13.3-27.2 (clayey soils) in the topsoil. On the other hand, in the subsoils, the CEC values range from 2.4-4.7 to 16.3-36.0 respectively. Both the contents of exchangeable cations and CEC in the studied soils decrease in the order: clayey soils > sandy loam soils > sandy clay soils > sandy-clay-loam hydromorphic soils > sandy-clay-loam well-drained soils > loamy sandy soils (Table 5). This is explained by a) higher contents inherited from the bedrock or substrate and b) higher CECs in heavy-textured soils where the predominant clay mineral is smectite (Dubroeucq, 1967; Volkoff, 1966; Igué, 1985; Igué, 2000, Junge and Skowronek, 2007). The clay mineral influence is also evidenced by the correlation between CEC and either kaolinite or smectite predominance. The good drainage in the high peneplains allows the formation of kaolinite and limits that of smectite (Boulet, 1974; Igué, 1985; Igué, 2000). CEC values are higher in soils of the low peneplains than soils in the high peneplains. Most profiles show a slight CEC increase due to higher clay contents with depth. The CEC of the topsoils increases significantly with the organic matter content. The correlation coefficient between CEC and organic carbon is R^2 = 0.74 was significant (Table 5). Woomer and Muchena (1993) showed a correlation coefficient of R^2 = 0.95 between organic carbon and total nitrogen and CEC in the Oxisols, Ultisols and Alfisols and concluded that the importance of the relationship between this soil characteristics in low activity clays is the opportunity for management whereas the lack of higher charged clays cannot be rectified.

The exchangeable cations figure after P and N among the most fertility-determining parameters for crops (Pichot et al., 1974). The mean weighted cation concentrations (cmol kg^{-1}) of each textural group follow the order: (Ca) > (Mg) > (K) > (Na) for LS/LS soils, for SL/SCL-well-drained soils and for L-CL/C soils. On the other hand for the SL/SCL gleyic soils the mean weighted cation concentration shows another sequence: (Ca) > (Mg) > (Na) > (K). The high content of Na in the last case is explained by high Na concentrations in the substrate as indicated above. Ca content tends to decrease with depth in LS/LS and SL/SCL soils but increases in soils with 2:1 lattice minerals (SL/SCL gleyic and L-CL/C soils). On the other hand Mg and Na tend to increase with depth in all soils but K tends to decrease. A marked difference in the levels of the individual exchangeable bases is found between clayey and sandy soils of otherwise similar morphology and this is illustrated by data quoted in Table 5. Levels of exchangeable potassium, calcium and magnesium are appreciably lower in the loamy sandy and sandy loamy topsoil. The generally lower levels of exchangeable nutrients in loamy sand soils are partially explained by the reduced exchange capacity of horizons having low clay content.

Potassium, the most important plant nutrient among the cations, is mainly contained in feldspars imported with dust but also seasonally biocycled so that it occurs in higher quantities in the topsoils (Geiger et al. 1992, Piéri 1989). In loamy sandy substrates it is highly prone to leaching. This is expressed by low K contents of 0.17-0.32 cmol kg^{-1} for LS/LS soils compared to 0.22-0.71 cmol kg^{-1} and 0.42-0.96 cmol kg^{-1} respectively for SL/SCL and L-CL/C soils. Together with sodium it is the first cation to be leached, which is evidenced by comparison with other cations. After Leihner et al. (1999), potassium has no significant effect on maize yield on Ferric Luvisols of gneiss basement. This is confirmed by Kayode (1986) who postulated 0.16 cmol kg^{-1} as the threshold to obtain an effect through potassium fertilizer application in the humid tropics. Hence, K-deficiency is not a limiting factor in the study area and may only occur for crops grown on loamy sandy soils in the terrain units Footslopes (on quartzite, granite, gneiss and rhyolite) or on high peneplains (on gneiss and myolite) with continuous cultivation (profile sets 6, 7, 8, 10 and 12; Tables 6 and 7).

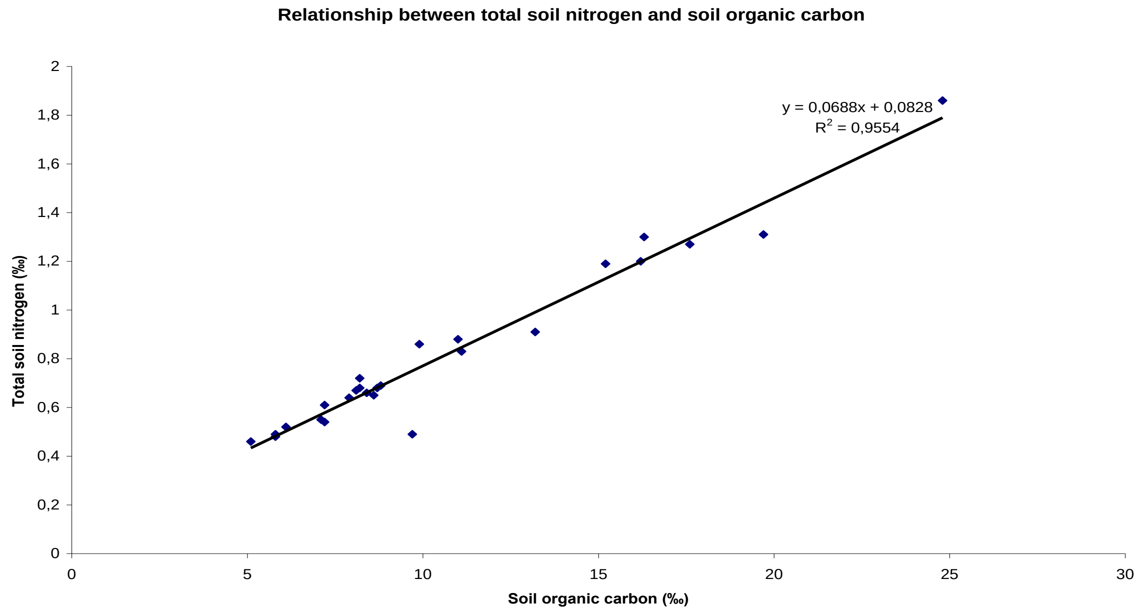

Figure 6: Relationship between total soil nitrogen and soil organic carbon

Table 6: Criteria of chemical fertility classes' evaluation

Characteristics	No limitations- I	Medium limitations-II	Sever limitations-III	Very sever limitations- IV
Organic carbon ‰	> 13	13-6	6-3	< 3
Total nitrogen ‰	> 0.8	0;8-0.45	0.45-0.3	< 0.3
P ppm (Bray 1)	> 20	20-10	10-5	< 5
K méq/100 g soil	> 0.4	0.4-0.2	0.2-0.1	< 0.1
Sum of cations	> 10	10-5	5-2	< 2
Base saturation %	> 60	60-40	40-15	< 15
CEC méq/100 g soil	> 25	25-10	10-5	< 5

Source: Dabin, 1956; Igué, 2004

Calcium and Magnesium are less important plant nutrients. The Ca and Mg contents in L-CL/C soils range between 4.8-21.4 cmol kg^{-1} (Ca) and 1.3-12.6 cmol kg^{-1} (Mg) , whereas in LS/LS soils 0.7-1.7 and 0.2-1.7 cmol kg^{-1} occur respectively. They are also less prone to leaching than K and Na. Thus Ca and Mg deficiency is not likely to occur in the study area, which can be explained by the parent material of the soils and by inputs through aeolian dust (Herrmann 1996).

Not only the total amount of cations is important, but also the ratio between the different cations. According to Sys et al. (1993) the optimum ratio between the three cations is 75/18/7. In the profile sets the ratio Ca/Mg varies between 1.8 to 4.7 and those Mg/K from 1.4 to 20.7. These values indicate that there is equilibrium between Ca, Mg and K in all soils in the study area.

Organic carbon, nitrogen and available phosphorus

Organic carbon and organic nitrogen content are widely used as a measure of organic matter (OM) quantity and quality in a soil, and as a crude measure of the fertility status (Landon, 1984). The interpretation of the content of the organic carbon and organic nitrogen is complex, because it is highly variable depending on terrain position, soil type, landuse, vegetation type and cover. Termites are considered together with micro-organisms as the main decomposing agents (Léonard and Rajot, 1998). Through their often spot-like activities they distinctly increase the micro-variability of carbon and nitrogen (Herrmann et al., 1994). Table 4 shows the total organic carbon content (C_{org}) of the profile sets. The averaged C_{org} for loamy sandy soils ranges from 5.1-11.0‰ in the upper 30 cm to 0.4-1.4 ‰ in the subsoil. For heavy-textured soils average C_{org} contents of 17.2 ‰ and 4.0 ‰ are reached respectively. The higher C_{org} content in heavy-textured soils can be attributed to a) stabilising organo-mineral complexes with clay particles (Schachtschabel et al., 1998), b) external influx of organic matter and stagnant water in alluvial positions (profile set 25) and c) landuse, vegetation type and cover (profile set 26). The highest values are attained with Leptosols (24.8‰), Vertisols on gabbro (19.7‰), Cambisols on basalt (17.6‰), Phaeozems (16.3‰) and Vertisols on gneiss (16.2‰). Arenosols on gneiss exhibit the lowest C_{org} contents (5.1 ‰) in the study area (Tables 6 and 7).

The total nitrogen content (Nt) is generally well correlated to the organic carbon content where correlation coefficient is R^2 = 0.96 (Figure 6). This leads to a mean C/N ration of 10-14, which indicates good conditions for N mineralisation. As in the case of C_{org}, the soils poor in nitrogen (profile sets 7, 8, 10, and 17) are Arenosols and Planosols mainly in the terrain units Footslopes (on gneiss), High peneplains (on granite) and on the sandy Plateaus on gneiss. A total nitrogen content above 1.2‰ is considered to be sufficient for most crops on neutral soils in the tropics (Pagel et al., 1982). Thus, the profile sets 13, 16, 21, 23 and 26 can be classified as rich in nitrogen. They occur almost exclusively in the Low peneplains on gneiss and gabbro.

The available phosphorus (Pa) indicates the P-fraction which can be easily assimilated and biocycled by plants. Pa contents of the topsoils are distinctly higher than those of the subsoils. This is attributed to the integration and release of P within the superficial biocycle (Hammer 1994, Geiger et al. 1992). P-status is high in weakly weathered Phaeozems. Generally in the study area, Pa is correlated with the OM content. Colluvial Arenosols, Phaeozems, and Leptosols (profile sets n° 9, 16, and 26) showed the highest Pa contents >25 mg kg^{-1} (Table 4). Leptosol are mainly found in mountainous areas (Tgn, Tg, Tgn), whereas Phaeozems occur as inclusions in Low and High peneplains on gneiss. Colluvial Arensols are dominant in footslope positions on gneiss and quartzite. Moderate availability (15-25 mg kg^{-1}) is found in profile sets 13 and 22 (Vertisols and Cambisols on gabbro) in the Low peneplains.

Table 7: Soil fertility in relation to landscape

TU	TC	Soil	pH	Corg ‰	N ‰	P	K	CEC	BS	Fertility	Limiting factors
Hills	Sgn	Leptosols	6.4	24.8	1.86	27.6	0.66	12.7	99	High	
Footslopes	Fb	Cambisols	6.4	15.2	1.19	13.2	0.42	16.9	82	High	
	Fg	Arenosols	6.3	5.8	0.49	3.8	0.17	4.5	60	Low	Corg, P, K , CEC
	Fq	Alisols	6.5	8.6	0.65	4.9	0.35	7.4	65	Medium	P, CEC
	Fgn	Arenosols	6.8	5.8	0.48	10.5	0.24	6.3	72	Low	Corg, N, P, CEC
	Fr1	Cambisols	6.5	8.7	0.68	13.8	0.30	11.2	69	Medium	
	Fr2	Luvisols	6.3	8.2	0.68	5.9	0.36	6.2	72	Low	P, CEC
	Fcr	Luvisols	6.3	7.2	0.61	3.4	0.27	5.8	82	Low	P, CEC
Plateaus	Pgn	Acrisols	6.8	7.9	0.64	11.6	0.35	7.3	73	Medium	CEC
	Pg	Arenosols	6.4	5.1	0.46	4.6	0.26	4.5	63	Low	Corg, P, CEC
High peneplains	Lgn	Luvisols	6.5	7.2	0.54	4.9	0.37	7.2	80	Low	P, CEC
	Lg	Regosols	6.5	6.1	0.52	4.2	0.19	4.8	77	Low	P, K , CEC
	Lm	Plinthosols	6.4	7.1	0.55	12.5	0.30	5.6	77	Medium	CEC
	Ls	Luvisols	6.3	7.2	0.61	3.4	0.27	5.8	82	Low	P, CEC
	Lr	Luvisols	6.6	7.2	0.61	3.4	0.27	5.8	82	Low	P, CEC
Low peneplains	Vgn	Gleysols	6.3	8.2	0.72	5.3	0.28	8.3	68	Low	P, CEC
		Vertisols	6.6	16.2	1.20	16.0	0.77	26.1	92	High	
		Cambisols	6.5	11.1	0.83	6.9	0.34	15.3	90	Medium	P
	Vga	Vertisols	6.5	19.7	1.31	19.4	0.42	30.2	94	High	
		Cambisols	6.4	9.9	0.86	8.0	0.32	14.8	88	Medium	P
	Vm	Solonetz	6.4	8.4	0.66	1.7	0.22	10.5	74	Medium	P
	Vc	Arenosols	6.7	11.0	0.88	33.7	0.32	6.4	80	Medium	CEC
Floodplains	Va	Fluvisols	6.0	13.2	0.91	13.0	0.34	11.4	67	High	

4. CONCLUSION

The properties of soils are highly variable within the moist savanna of Benin, especially with respect to chemical parameters. Depending on the location in the landscape, most severe limitations are posed by limited potential rooting depth (occurring in soils in mountain areas and on hills), high gravel content (certain soils on High peneplains), imperfect drainage (on Footslopes with basalt intrusions or in the Low peneplains on gneiss, gabbro and myolite) and flooding risk (Floodplains).

The levels of exchangeable bases in the topsoils (30 cm) of the study area are moderate to high. Levels of exchangeable calcium and magnesium are appreciably lower in loamy sandy and sandy loam topsoils, which can be partially explained by the reduced exchange capacity of horizons having low clay content. Nevertheless, the concentration levels of exchangeable bases in all topsoils are sufficient for crop production. The high degree of saturation is most probably related to the high proportion of scarcely weathered mineral fragments often apparent in the soil profiles and regular dust inputs through the Harmattan. The P status of the soils was found to be low, except in Colluvial Arenosols, Phaeozems, and Leptosols, occuring in footslope positions on gneiss and quartzite, High and Low peneplains on gneiss and in steep sloping areas, respectively. In the study area most soils are moderately rich to rich in nitrogen. Only some profile sets can be considered to be below the sufficiency level (profile sets of Arenosols on gneiss, granite, migmatite and Planosols). With regard to the chemical fertility parameters exchangeable bases, CEC, pH, P_{Bray}, N_t, C_{org}, a fertility sequence was established: Clayey soils on gneiss, basalt and gabbro basements > sandy loam alluvial soils > sandy clay soils on gneiss and gabbro > sandy-clay-loam hydromorphic soils > loamy sandy soils on colluvial deposits > sandy-clay-loam well-drained soils on all basements > loamy sandy soils on granite. Vertisols, Cambisols, Solonetz and Gleysols in the low peneplains are chemically most fertile, although they are only poorly cultivated by farmers due to difficulties in workability by hoe.

An importance factor in continuous productivity of tropical soils is the maintenance and improvement of soil physical characteristics. Once this is achieved, production capacity of these soils can be further improved by the use of organic and inorganic fertilizer (Woomer and Muchena, 1995)

The present investigation gives an overviwe over the soil fertility status in the moist savanna of Central Benin and demonstrates that there are close relationships between landscape/terrain units, profile sets that are distinguishable in the field and physical and chemical soil properties. The identification of these relationships and their assessment by the SOTER methodology may be useful for the quantification of soil fertility constraints and nutrient management options for scientists, extension services and institutions that are concerned with land use planning at the regional scale.

REFERENCES

Acres, B.D., Green, M.A., Rackham L.J., (1993) A method for identifying soil catenas and determining map unit composition used in a reconnaissance soil survey in Tanzania. Geoderma 57, 387-404.

Adam, K.S., Boko, M., (1983) Le Bénin - SODIMAS/EDICEF, 955; Strasbourg

Agbo, P. B. (1999) Restoring crop productivity in West Africa : the potential of agroforestry. Long-terme mulching and fertilizer effects on maize and cassava intercropping in the West Africa subhumid zone. Ph D thesis 139 p. Hohenheim Tropical Agricultural Series N°7 Margraf Verlag Germany.

Aicard, P., (1957) Le précambrien du Togo et du Nord-Ouest du Dahomey. Bull. Dir. Fédér. Min. Géol. Affr. Occ. Fr. No. 23. Dakar, Sénégal. 226 p.

Akondé, T. P. (1995) Potential of Alley Cropping with Leuceana leucocephala (Lam.) de Wit and Cajanus cajan (L.) Millsp. for maize and cassava production on an Acrisols in Benin Republic (West Africa) 166p. Hohenheimer

Bodenkundliche Hefte 25. Inst. Für Bodenkunde Uni-Hohenheim.

Azontondé A., Akakpo A., (2007a) Etude agropédologique à l'échelle de 1/25000 à Nagayilé (Bassila) (Département de la Donga). LSSEE, Etude n° 351. INRAB/MAEP/Bénin 27p.

Azontondé A., Akakpo A., (2007b) Etude agropédologique à l'échelle de 1/25000 à Adjandjangou dans la commune de Djougou (Département de la Donga). LSSEE, Etude n° 351. INRAB/MAEP/Bénin 35p.

Bello M., (2006) Dégradation des terres du bassin versant de Lotho dans la commune de Dassa-Zoumé (Bénin). Mémoire pour l'obtention du DIT/EPAC/UAC. 78 p.

Boulet, R., (1974) Toposéquences de sols tropicaux en Haute-Volta. Equilibre et déséquilibre pédobioclimatiques. Mémoires ORSTOM n° 85. 272p.

Dabin, B., (1956) Contribution a l´étude de la fertilité des terres de barre Agr. Trop. 11(4), 490-506.

Dubrouecq, D., (1967) Etude des sols de la région ouest Dassa-Zoumé. Etude no. 98. Centre Nationale d´Agropédologie, Bénin. 96p.

Ernst-Schaeben, R. (1994) Potential of alley cropping maize and cassavain south Benin West Africa. Evaluation of the establishing phase. Pp 131Ph D thesis University Hohenheim Institut für Pflanzenproduktion in den Tropen und Subtropen Verlag Ulrich E. Grauer Wendlingen.

FAO, (1990) Guidelines for soil profile description. 3rd edition. FAO; Rome. 70p.

FAO, (1998) World Reference Base for Soil Resources. World Soil Resources Reports Vol. 84. FAO Rome.

Fritz, C., (1996) Boden- und Standortsmuster in geomorphen Einheiten Süd-Bénins (Westafrika). Hohenheimer Bodenkundliche Hefte 29. Hohenheim University, Stuttgart, Germany. 143 p.

Hammer, R., (1994) Bodensequenzen und Standorteigenschaften im Südwest-Niger/Westafrica. Hohenheimer Bodenkundliche Hefte 22. Hohenheim University, Stuttgart, Germany. 145 p.

Herrmann, L., Hebel, A., Stahr, K. (1994) Influence of soil microvariability on millet growth on sandy sahelian soils. J. Plant Nutr. Soil Sci. 157, 111-115.

Herrmann, L., (1996) Staubdeposition auf Böden West Afrikas. Eigenschaften und Herkunftsgebiete der Stäube und ihr Einfluß auf Böden und Standortseigenschaften. Hohenheimer Bodenkundliche Hefte 36. Hohenheim University, Stuttgart, Germany. 236 p.

Gaiser, T. (1993) Bedeutung der organishen Bodensubstanz für Eigensschaften und Ertragfähigkeit von Vertisolen und Acrisolen in Süd-Benin: Hohenheimer Bodenkundliche Hefte 12, University Hohenheim, Stuttgart 168p.

Gaiser, T., Weippert H., Igué A.M., Stahr K (2006) Application of the land resources information system SLISYS in the Oueme basin of Benin (West Africa). Conference on International Agricultural Research for Development, Tropentag 2006. and Poverty in a globalized world: Challenges for Agricultural Research; Book of Abstract p.296, F. Asch and M. Becker (eds.). www.tropentag.de

Geiger, S.C., Manu, A., Bationo A., (1992) Changes in sandy Sahelian soil following crop residue and fertilizer additions. Soil Sci. Soc. Am. J. 56, 172-177.

Igué, A.M., (1985) Analyse structurale et représentation cartographique d´une couverture ferrallitique du bassin versant sur formations schisteuses á Lokpasso en Côte-d'Ivoire.148p. Mémoire DESS ORSTOM. Paris.

Igué, A.M., (1992) Utilisation des données pédologiques pour une agriculture durable. Cas des terres de barre au sud Bénin. World Soil Resources Reports n° 83 pp 109-127, Rome.

Igué, A. M., Weller, U., Stahr, K. (1999) The SOTER database-Benin. In: Renard, G., Krieg, S., Lawrence, P., von Oppen, M. (Eds), Farmers and Scientists in a changing environment: Assessing Research in West Africa. Margraf Verlag, Germany. pp.215-222.

Igué, A. M., (2000) The use of a soil and terrain digital database for land evaluation procedures. Case study of Central Benin. Hohenheimer Bodenkundliche Hefte 58 235p. University of Hohenheim, Stuttgart, Gemany

Igué, A.M., Azontondé A., Yousouf I. et Lawani M. (2001) Etude agro pédologique des périmètres pilotes de la Sota (PAHVN-PP) dans cadre Projet Aménagement Hydroagricole dans la vallée du Niger. LSSEE, Etude n° 338. INRAB/MAEP/Bénin 37p + Annexes 66p.

Igué, A. M., Gaiser, T., Stahr, K. (2003) A soil and terrain digital database (SOTER) for improved land use planning in Central Benin. Europ. J. Agronomy 21 41-52.

Igué A. M. (2004) Fertilité des terres de barre à Adingnigon (commune d'Agbangnizoun). In Actes de l'Atelier Scientifique National 4 du 14 au 17 décembre 2004. Edité par : A. Adjanonhoun, C. Bankolé, B. Agbo et K. Igué. Pp 246-252. ISBN 99999-51-68-7.

Igué, A. M., Gaiser, T., Stahr, K. (2004) Suitability of Climate, Soil and Landscape Units for Crop Production in the Moist Savanna of Benin Republic. DIE ERDE 134 (4) S. 395-408.

Igué A. M., (2005) Soil information system for the Oueme basin. http://www.rivertwin.de/assets/publications/D15_ SLISYS_Oueme basin2.pdf.

Igué A. M., Dagbérou R. P., (2007a) Etude agropédologique à l'échelle de 1/25000 à Miniffi dans la commune de Dassa Zoumé (Département des Collines). LSSEE, Etude n° 351. INRAB/MAEP/Bénin 46p.

Igué A. M., Dagbérou R. P., (2007b) Etude agropédologique à l'échelle de 1/25000 à Gbanlin et Atata dans la commune de Ouessè (Département des Collines). LSSEE, Etude n° 352. INRAB/MAEP/Bénin 34p

ISRIC, (1993) Global and national soils and terrain digital databases (SOTER): procedures manual. Van Engelen, V.W.P, Wen, T.T. (Eds.), International Soil Reference and Information Centre (ISRIC). Wageningen, The Netherlands. 115 p.

ISRIC, (1997) Soil map of the world. Revised legend with corrections. Technical Paper 20. ISRIC, Wageningen. 140p.

Junge B., (2004) Die Böden des oberen Ouémé-Einzugsgebietes in Benin/Westafrica - Pedologie, Klassifizierung, Nutzung und Degradierung. Diss. Landw. Fak. Univ. Bonn. 291p.

Junge B., Skowronek, A., (2007) Genesis, properties, classification and assessment of soil in Central Benin, West Africa. Geoderma 139, 357-370.

Kayode G.O., (1986) Further studies on the response of maize to K-fertilizer in the tropics. J. Agric. Sci. 106, 141-147.

Landon, J. R., (1984) A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Booker Agriculture International Limited (BAI). 450 p.

Leihner, D.E., Bernard, M., Doppler, W., (1999) On-farm Evaluation of Soil Fertility Management Practices in Southern Benin. In: Special Research Programme 308 Adapted Farming in

West Africa. Report of Results 1997-1999, University of Hohenheim, Germany. pp. 349-376

Léonard, J. and Rajot J. L., (1998) Réhabilitation par paillage des propriétés d´infiltration de sols encroutés. In Renard, G., Neef, A., Becker, K., von Oppen, M. (Eds.), Soil Fertility Management in West Africa Land Use Systems. Margraf Verlag, Germany. pp. 191-196.

Levêque, A., (1979) Pédogenèse sur socle granito-gneissique du Togo. Différenciation des sols et remaniements superficiels. Travaux et documents de l' ORSTOM, n° 108, Paris. 224 p.

Maeir R. (2004) Standortseignung fur Baumwolle in einer Kleinlandschaft in zentralbenin. Studienarbeit der Agrarwissenechaften (B.Sc.). Universität Hohenheim, Stuttgart Germany. 43 p.

OBEMINES (1989) Carte géologique du Bénin à 1:200 000. Office Béninoise des Mines. Cotonou, Bénin

Pagel, H., Enzmann, J., Mutscher, H., (1982) Pflanzennährstoffe in tropischen Böden – Ihre Bestimmung und Bewertung. VEB Deutscher Landwirtschaftsverlag, Berlin. 270 p.

Piéri, C., (1989) Fertilité des terres de savanes. Bilan de trente ans de la recherche et de développement agricoles au sud du Sahara. Ministère de la Coopération et du Développement, CIRAD, Paris. 44p.

Pichot, J., Burdin, S., Charoy, J., Nabos, J. (1974) L´enfouissement des pailles de mil Pennisetum dans les sols sableux dunaires. Agron. Trop. 29, 995-1005.

Pougnet, R., (1957) Le précambrien du Dahomey. D.F. du Min. et de la Géographie de l´Afrique Occidentale Française. Bulletin n°22. Dakar, Senegal.

Roose, E. (1976) Le problème de la conservation de l´eau et du sol en République Populaire du Bénin. FAO/ORSTOM. Abidjan. 34 p.

Schachtschabel, P., Blume, H.-P., Brümmer, G., Hartge, K.-H., Schwertmann, U., (1998) Lehrbuch der Bodenkunde. 14th edition. Enke Verlag, Stuttgart. 494p.

Steup, G., (2008) Hydrological Processes and Soil Distribution in the Ara Catchment. In Impetus Atlas Benin. Second Edition. pp 77-78. Impetus Project. Universität Bonn. ISBN-13978-3-9810311-5-7.

Sys, C., (1976) Principes de classification et d´évaluation des terres pour la Rép. Pop. du Bénin. Rapport de mission de consultation FAO. Etude N° 152. CENAP, Cotonou, Bénin.

Sys, I.C., van Ranst, E., Debaveye, J., Beenaert, F., (1993) Land evaluation, Part III: Crop requirements, Agricultural Publications, General Administration for Development Cooperation, Brussels.

Ter Kuile, C. H., (1983) Système de culture "L´exploitation en zone tropicale". Le courrier N° 82. Décembre 1983.

Tran Vin An (1976) Recueil des méthodes d'analyses des sols : principes, techniques et calculs. Projet d'agro-pédologie. Etude N° 156. LSSEE/INRAB/MAEP, Cotonou, Bénin 54p.

Volkoff, B., Willaime, P. (1965) Notice explicative de la carte des sols au 1/1.000.000 de la République du Dahomey. Mission d´Etudes au Dahomey. ORSTOM, Paris 66p.

Volkoff, B., (1966) Les sols de la région Ouest Savalou à 1:100 000. Etude no. 91, CENAP, Bénin. 64 p.

Volkoff, B. (1976) Carte pédologique de reconnaissance de la République du Bénin à 1/200.000. Feuille Abomey. ORSTOM, Paris. Notice explicative 66(1). 39 p.

Weller, U., and Stahr K. (1995) Einer Standorts karte für Südbenin- Erfassung von Geländeeigenschaften und Bodenparametern. Mitteilg.d. Dtsch. Bodenkdl. Ges. 76. pp 1221-1224.

Weller, U. (2002) Land Evaluation and Land Use Planning for Southern Benin (West Africa). Hohenheimer Bodenkundliche Hefte. Heft N° 67 p. University of Hohenheim, Stuttgart, Gemany. ISSN 0942-0754; 166 p.

Woomer P. I. and Muchena F. N. (1995) Overcoming soil constraints in crop production in tropical Africa. In Seminar proceedings on sustaining soil productivity in intensive Africa agriculture. Ahenkorah Y., Owusu-Bennoah E., Dowuona G.N.N. (editors) Accra Ghana. CTA, pp45-56. ISBN 92-9081-138-2.

Yousouf I., Azontondé A., Igué, A.M. et Lawani M. (2001) Etude pédologique au 1/2000^{e} de la basse vallée du Mono dans cadre Projet d'Aménagement Hydro Agricole de la Basse Vallée du Fleuve Mono. Etude N° 339 CENAP, Cotonou 73p. + Annexes 85p.