published by

EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 66 (2025): 1-17
Journal homepage: https://eqa.unibo.it/

Quality and fertility status of soils in the groundnuts (*Arachis hypogaea* L.) production basin of Ngong, North Cameroon

Gabriel Ange Teguia Kamdem[1,2*], Jacques Roberto Tueche[2], Robert Temdjim[1], Lawrence Tatanah Nanganoa[3], Simon Djakba Basga[4], Cedrick Nguemezi[5], Paul Tematio[5]

[1] Department of Earth Sciences, Faculty of Science, University of Yaoundé, Yaoundé, Cameroon
[2] Institute of Agricultural Research for Development, Yaoundé, Cameroon
[3] Institute of Agricultural Research for Development, Ekona, Cameroon
[4] Institute of Agricultural Research for Development, Maroua, Cameroon
[5] Department of Earth Science, Faculty of Science, University of Dschang, Dschang, Cameroon

[*] Corresponding author E-mail: gkamdemteguia@yahoo.com

Article info
Received 31/7/2024; received in revised form 6/11/2024; accepted 15/11/2024
DOI: 10.6092/issn.2281-4485/20147

Abstract

Ngong is a famous groundnut *(Arachis hypogaea* L.) producing locality in Cameroon, contributing to the supply of local markets and neighboring countries. Official figures showed gradual yield decrease over recent years, attributable to various factors, with poor soil conditions among the most acute. However, missing information on soil quality and fertility status in these areas is jeopardizing efforts of improving agricultural productivity. This study aimed to assess the soil fertility status in the groundnut production basin of Ngong. Three main ground-nut production areas (Douka-longo, Tamoundé1, and Sabongari) of the basin were selected and twenty-three topsoil samples (0 – 30 cm) collected. Soil fertility attributes (index of structural stability (ISS), index of soil sealing (IB), Forestier index (IF), aluminium toxicity (m) and Soil Quality Index (SQI)) were assessed. The studied sites were effectively poor in soil fertility, having very low values of N, P, K, S, and cation exchange capacity (CEC). These soils are under high risk of degradation because of the low soil aggregate stability (ISS < 9%) and fertility (IF < 1.5) indexes. The SQI ranged from 0 to 0.4 indicative of poor fertility with degraded soil condition. The main factors controlling soil quality include Ca, pH, organic matter (OM), available P, total Nitrogen and CEC. Long-term maintenance of soil quality requires better integrated soil fertility management practices. Optimal soil nutrients management system such as the application of organo-mineral amendments rich in N P, K, Ca and Mg to promote plant root establishment, which will also improve the soil structure should be considered to enhance the soil fertility status along with the inclusion of good cultivars for yield improvement.

Keywords
soil fertility; soil quality, soil indicators, Ngong, groundnut production

Introduction

Soil is the essential primary resource for agriculture and the natural surface of the earth, differentiated into different layers (pedological horizons), with a losle structure of mineral and/or organic constituents (Gobat et al., 2003). Soil components are the result of the transformation of the underlying parent rock, under the influence of various physical, chemical, and biological processes (Demolon, 1932). The physico-

DOI: 10.6092/issn.2281-4485/20147

cotton, and millet), livestock (cattle, poultry) and chemical properties of soils are subjected to decay over time due to several factors. The common factors of soil degradation and decline fertility are climate, anarchic land use practices and the lack of accurate data to support sustainable soil management (Barbier et al., 2003; Partey et al., 2011). Studies carried out by many authors on the assessment of soil fertility in the North of Cameroon (Mathurin et al., 2003; Olina Bassala et al., 2008; Roland, 1986) highlighted the decline in soil nitrogen content and the insufficiency of available phosphorus, to which other elements are added (Amani et al., 2022). Despite these studies, there is still a lack of accurate soil information about the quality of soil to sustain sustainable agricultural production initiatives at local level. Knowledge of soil quality and fertility in this region is essential for sustainable agricultural production. For example, the spatial distribution of soil types and/or soil parameters and soil fertility is an indispensable first step in obtaining reliable baseline data to facilitate all subsequent agricultural productivity breakthroughs. A productive and sustainable agricultural system is fundamental to the well-being of the country (SDN 30, 2020). Declining soil fertility necessarily leads to lower crop yields as reported for groundnut production in Cameroon. Groundnut (*Arachishypogaea* L.) is an important source of lipids, proteins and minerals in human and animal diets. The grain contains on average 45-50% fat, 25-30% protein, 5-12% carbohydrate and 3% fibre (Griel et al., 2004). They are mainly processed into several by-products (flour, peanut butter, hulled peanuts, salted peanuts, etc.) which are very important for human consumption. (Hubert, 2010).In addition to its importance in human and animal nutrition, groundnut is also used in the soap industry and medicine. Furthermore, groundnut is a leguminous plant, with capacity of enrichment of the soil with nitrogen through biological nitrogen fixation (Kamdem et al., 2020, Nanganoa et al., 2019). It can be used as a green manure in agriculture (Aguieb and Messai, 2015). In Cameroon, groundnuts is produced in all regions and used as a cash crop as well as a subsistence food crop by smallholder farmers (Seraphin et al., 2015). However, like many other crops, it is subjected to a number of constraints such as increasingly irregular rainfall, lack of financial resources, access to land and declining soil fertility (Aguieb and Messai, 2015; Hamasselbé, 2008; Mathurin et al., 2003). The 2017 official statistics report from the National Statistics Institute of Cameroon (INS) has reported a gradual yield decrease over recent years, which could be attributable to the factors above, with poor soil conditions among the most acute. Groundnut production in Cameroon can be increased to satisfy demand for this crop through knowledge of soil quality and fertility. The objective of this study is to assess the quality and state of soil fertility in the agricultural production areas of Ngong in order to identify the most important factors that influence agricultural production.

Materials and Methods

Study area

The study area is in the municipality of Ngong. It extended between latitudes 9°00' and 9°10' N and Longitudes 13°30' and 13°45' E (Fig. 1C). The area is in the Benoue plain, where groundnut production is commonly practiced in rainfed condition by local farmers. The climate is tropical of the Sudano-Sahelian type, characterized by mono-modal rainfall varying between 800 mm and 1300 mm annually (Nguemhe Fils. et al., 2014).This climate is characterized by two seasons: a dry season lasting seven months (November-May) and a rainy season lasting five months (June-October) (Offossou, 2011). Temperatures vary according to the seasons, with an annual average of 28 °C, and the maximum ranging from 40 to 45 °C in April (Offossou, 2011). The vegetation of the study area is a shrubby Sudanian savannah with the appearance of clear and degraded savannah around the villages, with a higher density around the hunting zone (Offossou, 2011). The study area is crossed by a few watercourses, the most important being the Mayo-Douka.

Soils and pedogenic substrates

The geological formation covering about 95% of the territory is the Garoua sandstone (Cretaceous). All these sandstones are intercluded in some places by volcanic formations which are the trachyte (Schwoerer, 1965). The study area is surrounded by lowlands with specific soil characteristics (Brabant and Humbel, 1974). According to the IUSS WRB2022 and De Pauw, 2019 studies, the main soil groups identified are Lixisol (40%) and Arenosol (30%). The remaining 30% are stagnosols, gleysols, fluvisols, leptosols and plinthosols (Fig. 1C). It should be noted that these are young soils that are still in the process of formation; the diversity of soils here can be explained by parent rock, altitude and climate. Agriculture (groundnuts,

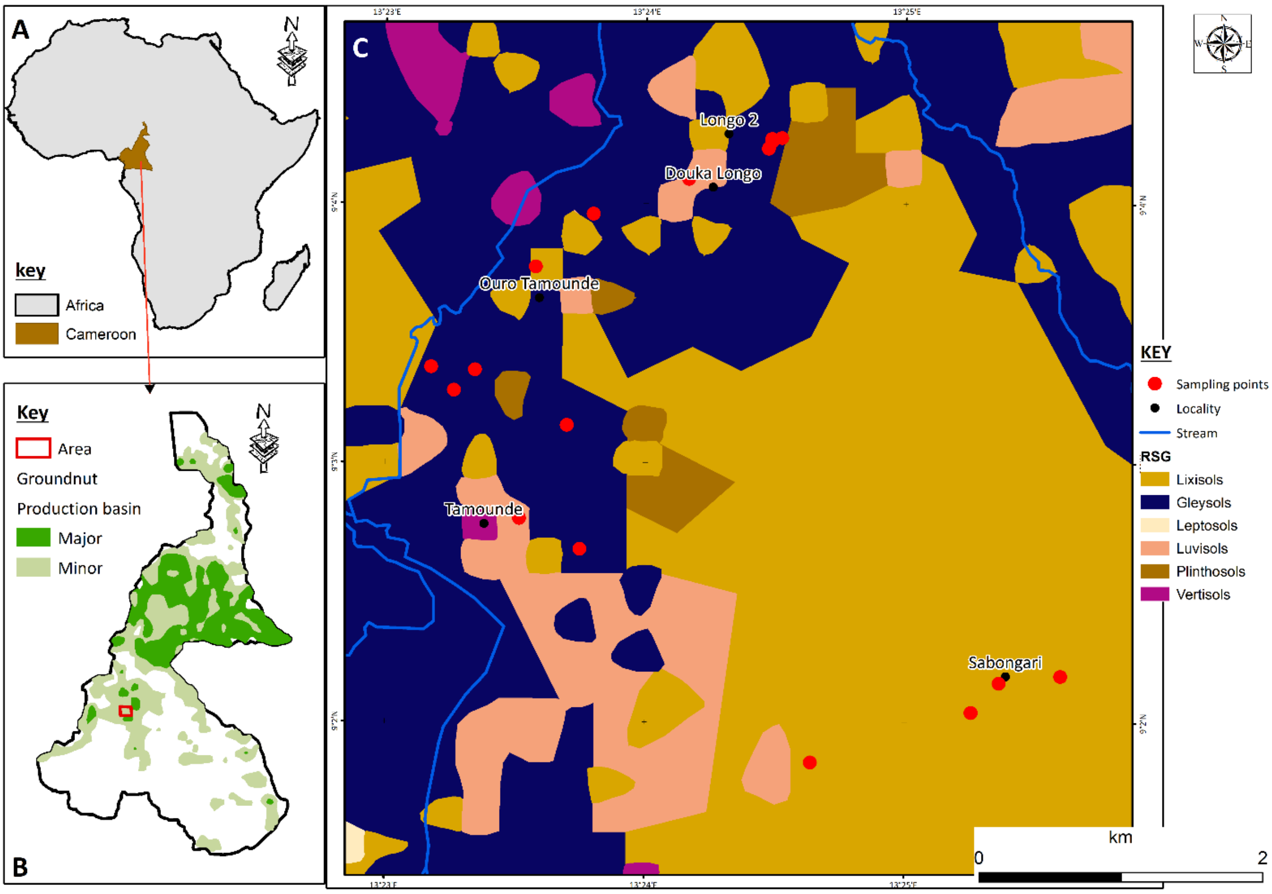

Figure 1. *Localization of the study area (A: map of Cameroon in Africa; B: Main production basin of groundnut in Cameroon; C: Study sites).* (Source Poggio et al,, 2021 modified)

small trade are the main livelihoods of the populations. Study area includes three (03) sites in the municipality, well known for their high implication on groundnut production namely: Douka-longo, Sabongari and Tamoundé. In those sites, groundnut cultivation is semi-mechanized. Ploughing is performed by oxen on which disc ploughs are mounted.

Soil sampling and analyses

To carry out our study, a field survey for soil samples collection was carried out. In the field, 23 soil samples were collected at 0 – 30 cm deep with hand auger in the groundnut production plots in the three main study sites, and distributed as follows: Douka-Longo (7), Sabongari (8) and Tamoundé (8). In each sampling plot, composite disturbed samples were taken from the surface horizon (0 – 30 cm) for physico-chemical analysis. Composites were built out of the random collection and mixture of five subsamples within a plot. Undisturbed soil samples for bulk density assessment were collected with cylinders at corresponding depths. Physico-chemical analyses were carried out at the Soils, Plant and Water analytical laboratory of Institute of Agricultural Research for Development (IRAD), Yaoundé. Soil samples were air-dried, then crushed and sieved to 2 mm and 0.5 mm. The bulk density was obtained from undisturbed soil samples using the Koppeki cylinder method (Blake, 2015). Grain size analysis was obtained by the Robinson Khön pipette method (Beverwijk, 1967; Day, 2015). Soil chemical analyses such as pH, total nitrogen, organic carbon, total and available phosphorus, exchangeable bases (Ca, Mg, K, Na), CEC, and exchangeable aluminium were conducted. Organic carbon was determined by chromic acid digestion and spectrometric analysis (Heanes, 2008). The determination of total Nitrogen was done by the method of Kjeldahl. The organic matter content was obtained by multiplying the organic carbon content by the Sprengel factor which is 1.724 for cultivated lands. . The available phosphorus P was extracted using the Bray II procedure and the resulting extract was analyzed using the molybdate blue procedure as described by (Murphy and Riley, 1962). The pH was measured on a soil-water suspension at a ratio of 1/2.5 (w/v), using a pH meter equipped with a glass electrode. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were determined by Atomic Absorption Spectroscopy after extraction by ammonium acetate (CH_3COONH_4) using percolation method at pH 7. CEC was determined using a 1N solution of ammonium acetate at pH 7 following these steps: Saturation of the complex by $NH4^+$ ion and extraction of exchangeable bases; Leaching with alcohol in order to eliminate saturated solution; Transfer of $NH4^+$ ion by saturation of complex with a solution of 1N KCl; Titration of $NH4^+$ after quantitative desorption by K^+.

Soil fertility assessment

The fertility status was assessed based on computed fertility parameters using the physico-chemical properties. Physical parameters of soil fertility considered in this study are the index of structural stability (ISS) and the index of soil sealing (IB) while the chemical parameters were the Forestier index (IF) and the aluminum toxicity (m). In addition to these parameters, the interactions between exchangeable bases of the soil were depicted. These were the Ca/Mg, K/Mg, Ca/K and (Ca+Mg)/K ratios. The equilibrium between certain soil properties as established by FAO (FAO, 2006) was also investigated. Our study focused on the textural diagram, it should be noted that groundnuts grow well on soils that are fine-textured, loosed and permeable, preferably sandy soils (Hachim, 2020). The Forestier index (Forestier, 1960)can be used to assess the soil nutrients contents. Soil equilibrium such as Dabin's N-pH equili-brium (Dabin, 1961), Martin's Ca-Mg-K equilibrium (Martin, 1979) and Ca-Mg, S/CEC-pH equilibrium have been established. We investigated the aluminium toxicity using the Kamprath index (m), index of struc-tural stability (ISS) the index of structural stability al-lows to evaluate the susceptibility of soil aggregates to destruction when subjected to fluid action (Emerson, 1976). The formula for ISS is:

$$ISS = \frac{OM}{(L + A)} \text{ x } 100 \qquad [1]$$

where, OM the organic matter content; A , the clay fraction (%); L, the silt fraction (%). Values of ISS are translated to soil information as follows: For a value of ISS ≤ 5%, the soil has a degraded structure; for values between 5% < ISS ≤ 7% the soil is at high risk of degradation, for values between 7% < ISS ≤ 9%, the soil is at low risk of structural degradation, and for values above 9% (ISS ≥ 9%) translate a soil with a stable structure. The soil sealing index (IB) is rela-ted to the risk of soil to erosion, expressed as the sensitivity to compaction. From the agronomic standpoint, it slows down water supply and soil respiation to the detriment of its biological life and productivity. It is estimated using the Remy and Marin-Laflèche formula (1974):

$$IB = \frac{(1.5xLf) + (0.75xLg)}{(A - 10 \times OM)} - C \qquad [2]$$

where, $C = 2.0 \times (pH - 7)$, Lf(%) is the fine silt; Lg(%) the coarse silt; A(%) is the clay fraction and OM (%) is the organic matter content.

The values of the IB greater than 1.8 reflect a soil with a high risk of erosion. Values between 1.6 < IB ≤ 1.8 reflect a soil with a medium risk of erosion, and the values between 1.4 < IB ≤ 1.6 reflect a soil with a low risk of erosion. For values of IB lower than 1.4 (IB < 1.4) the soil has no risk of erosion. The Forestier index gives information on the reserve of exchangeable bases in the soil. It is calculated from the formula of Forestier (1960)

$$IF = \frac{S^2}{A + Lf)} \qquad [3]$$

where, S = the sum of exchangeable bases in meq/100g of soil; A: the clay fraction; Lf: the fine silt fraction. For values of the Forestier indices lower than 1.5 (IF <1.5) this reflects a soil poor in nutrients. For values above 1.5 (IF >1.5) the soil reflects a good soil nutrient reserve. Aluminum to-xicity is defined by the Kamprath index (Kamprath, 1970). It is calculated from the following formula:

$$m = Al^{3+} x \frac{100}{S + Al^{3+}} \qquad [4]$$

Where, Al^{3+} the concentration of exchangeable aluminum in meq/100 g of soil; S: the sum of exchangeable bases in meq/100 g of soil. If m < 20% the soil does not have Aluminum toxicity. For values of m between 20 < m (%) < 50, they reflect a soil with high Aluminum toxicity. When the values of m are greater than 50% (m≥50%), the soil has a very high toxicity in aluminum. In addition to these parameters, the sum of exchangeable bases (SBE) and the cation

DOI: 10.6092/issn.2281-4485/20147

exchange capacity (CEC) were considered in our assessment. They were classified after Beernaert and Bitondo (1992). If the values of the sum of exchangeable bases are SBE < 2 meq/100 g, the level is very low; $2 <$ SBE < 5 meq/100 g, the level is low; $5 <$ SBE < 10 meq/100 g, the level is moderate, $10 <$ SBE < 15 meq/100 g, the level is high and if SBE $\geq$.15 meq/100 g, the level is very high. With regard to the cation exchange capacity, Beernaert and Bitondo, 1992 also divided CEC values into different levels: if the CEC values are less than 5 (CEC$<$5 meq/100 g), the level is very low; $5 <$ CEC < 10 meq/100 g low level; $10 <$ CEC < 25 meq/100 g moderate level; $25 <$ CEC < 40 meq/100 g high level and if the values are greater than 40 (CEC ≥ 40 meq/100 g), the level is very high.

Balances between soil fertility parameters

Balances were assessed between physico-chemical properties of the soils. These are the textural class, pH, and cation balances plotted on diagrams according to the models used by FAO (Food and Agriculture Organization of the United Nations., 2006), Forestier (1960), Dabin (1961), and Martin and Sieffermann (1966). The textural diagram of FAO (2006) indicates the different textural classes of soils. The triangular diagram of Dabin (1961) indicates the poles of relative richness in Ca^{2+}, Mg^{2+}, and K^{+} cations and thus gives the cationic equilibrium of the three cations. The soil pH is a measure of the concentration of free H^{+} protons in the soil solution; the more H^{+} ions there are, the less cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) there will be in the soil. The more acidic the soil is, the less exchangeable bases it contains. The pH directly influences the chemical reactions in the soil and the availability of nutrients in a form that can be assimilated by plants, and indirectly influences plant growth. Dabin's (1961) diagram defines soil fertility with reference to soil pH and total soil nitrogen content. Soil pH is closely related to the sum of the bases present in the soil (Meyim, 2000). The binary diagram of Dabin (1979) makes it possible to highlight the antagonism or the synergy between K^{+} and Mg^{2+}; regarding the two other cations, namely Ca^{2+} and Mg^{2+}, a clear antagonism is noted between the two; the presence of one favors the absorption of the other by the roots and conversely.

Computation of soil quality index (SQI)

Calculating soil quality consists in combining the soil properties in response to variations in soil conditions (Brejda et al., 2000). The different steps to calculate the SQI have been described in previous works of Ngo-Mbogba et al., (2015) and Brejda et al. (2000). Principal component analysis (PCA) is applied for soil indicators selection. PCA is a factorial analysis in the sense that it produces factors (or principal axes) that are linear combinations of the original variables, hierarchical and independent of each other (Béguin and Pumain, 2000). It is an effective tool for summarizing and interpreting large quantities of data (Guerrien and Marc, 2003). With reference to previous work in Cameroon, soil indicators were selected for this study (Brejda et al., 2000; Nyeck et al., 2018). These are OM, pH water, CEC, Ca, Mg, K, C/N ratio, available P, Al and N. These dataset indicator focused more on soil chemical parameters, as authors such as (Yemefack et al., 2006) represented their utmost important influence for crops growth. Each indicator was normalized and the SQI parameter was calculated by the method described by Equation [5] (Andrews et al., 2002):

$$SQI = \sum_{i=1}^{n} WiXi \qquad [5]$$

where, W is the normalized indicator, X is the indicator score, SQI is the soil quality index; i is a soil property and n, the number of soil properties.

Soil fertility status

To assess the Soils fertility status in the study area, we use the classification proposed by Quemada and Cabrera (1995) and completed by Mamouda et al. (2021) and Nguemezi et al. (2020). The criteria for the evaluation of soil fertility classes are:

- Class I: soil characteristics do not have or have only weak limitations;
- Class II: soil characteristics do not have more than 3 moderate limitations possibly associated with low limitations;
- Class III: soil characteristics have more than 3 moderate limitations possibly associated with a single severe limitation
- Class IV: soil characteristics have more than one severe limitation.

Statistical analysis

For each variable studied, the data collected were entered in a Microsoft Excel 2013 spreadsheet. These data were transferred to SPSS.26 software for analysis of variance (ANOVA) and means were separated using Tukey's post hoc test at 5% probability

DOI: 10.6092/issn.2281-4485/20147

level. Statistical analyses were preceded by normality check and some data were transformed to follow normal distribution.

Results and discussions

Summary statistics of soil variables

The statistics of the 25 soils variables are summarized in Table 1. Most of them showed positive skewness varying between 0.18 and 2.13, except for pH water, Mg, C/N, IB, sand, (Ca + Mg)/K and BD, with negative skewness varying between -1.05 and - 0.02. The kurtosis were also varying, though most of the variables had slight deviation from the normal distribution (Lix et al., 1996). Except for pH water, C/N, sand, and BD with coefficients of variation (CV) of 6.33%, 11.84%, 2.78% and 1.62% respect-tively, all other variables showed high to very high CV, which means that there is a high variability of soil parame-ters within the groundnut production area. This fin-ding corroborates that of Nanganoa et al. (2020) who reported a similar variability of those soil properties while assessing the soil nutrients variability the area. The results of ANOVA along with the mean separation (Turkey's test) are presented in Table 2.

Table 1. *Site variability of soils properties and fertility parameters*

Stats	min	max	mean	SD	CV (%)	Skewness	Range	Kurtosis
OM (%)	0.54	1.33	0.80	0.20	24.51	1.14	0.79	0.97
N (%)	0.02	0.04	0.03	0.01	28.52	0.95	0.03	-0.07
P (ppm)	0.02	4.53	1.07	1.51	141.27	1.09	4.52	-0.29
pHw	4.70	5.69	5.19	0.33	6.33	-0.23	0.99	-1.59
Ca (Cmol(+)/kg)	0.12	1.24	0.48	0.30	62.01	0.99	1.12	0.50
Mg (Cmol(+)/kg)	0.05	0.23	0.16	0.04	26.02	-0.58	0.18	0.66
K (Cmol(+)/kg)	0.03	0.10	0.06	0.02	32.61	0.39	0.08	-0.12
Al (Cmol(+)/kg)	0.06	0.33	0.16	0.11	69.79	0.55	0.27	-1.63
C/N	13.44	23.11	18.63	2.21	11.84	-0.02	9.67	0.28
S (Cmol(+)/kg)	0.24	1.58	0.74	0.34	45.33	0.93	1.35	0.47
CEC (Cmol(+)/kg)	0.73	5.71	1.94	1.04	53.68	2.13	4.98	6.82
S:CEC (%)	0.08	0.89	0.44	0.20	46.43	0.62	0.81	0.12
IF (%)	0.00	0.18	0.05	0.04	89.77	1.68	0.17	3.05
ISS (%)	4.29	10.11	5.78	1.59	27.43	1.52	5.82	1.86
m (%)	4.23	48.44	20.30	16.13	79.44	0.50	44.21	-1.64
IB (%)	-76.10	52.53	5.18	25.60	493.99	-1.05	128.63	3.63
Sand (%)	80.46	90.38	85.58	2.36	2.76	-0.48	9.93	0.36
Clay (%)	5.62	10.97	7.74	1.41	18.24	0.60	5.35	-0.14
Silt (%)	3.57	9.57	6.68	1.57	23.58	0.18	6.00	-0.32
(Ca+Mg)/K	3.39	20.97	11.52	5.55	48.18	-0.14	17.58	-1.46
BD (g.cm-3)	1.58	1.69	1.63	0.03	1.62	-0.15	0.12	0.70
K/Mg	0.19	0.72	0.39	0.15	38.06	0.97	0.53	0.37
Mg/K	1.39	5.14	2.94	1.03	34.97	0.46	3.75	-0.30
Ca/Mg	1.29	5.29	2.78	1.18	42.69	0.50	4.00	-0.82
SQI	0.13	0.9	0.47	0.23	0.50	0.01	1.02	0.022

DOI: 10.6092/issn.2281-4485/20147

Table 2. *Soils chemical characteristics of the surface layer (0–30 cm) sampled at different sites*

Sites	Mo %	CEC	ISS	IF	IB-C	PH	P (ppm)	Ca	Mg	K	C/N
1	0.7 ± 0.1^{b}	1.6 ± 0.7^{a}	5.8 ± 1.9^{a}	0.03 ± 0.01^{b}	12.3 ± 24.8^{a}	5.2 ± 0.3^{b}	0.98 ± 1.8^{a}	0.4 ± 0.1^{b}	0.14 ± 0.05^{b}	0.04 ± 0.008^{c}	$19.\pm2.5^{a}$
2	0.9 ± 0.2^{a}	2 ± 1.6^{a}	6.3 ± 1.9^{a}	0.02 ± 0.01^{b}	-7.1 ± 29.8^{b}	4.8 ± 0.1^{c}	1.49 ± 2.04^{a}	0.2 ± 0.04^{b}	0.14 ± 0.02^{b}	0.08 ± 0.02^{a}	18.1 ± 2.5^{a}
3	0.8 ± 0.2^{b}	2.2 ± 0.7^{a}	5.3 ± 0.9^{a}	0.09 ± 0.04^{a}	10.6 ± 20.4^{a}	5.6 ± 0.1^{a}	0.76 ± 1.2^{a}	0.8 ± 0.2^{a}	0.2 ± 0.02^{a}	0.06 ± 0.006^{b}	$18.7\ \pm1.9^{a}$

Values followed by the same letters in the same column are not statistically different ($p < 0.05$) according to Tukey's test. Site1: Douka-Longo; Site2: Tamoundé; Site3: Sabongari

Regarding the physical fertility parameters, the index of structural stability (ISS) did not show any signifycant difference between the sites (Table 2). However, those ISS values (< 9%) are indicative of a high risk of soil degradation (Beernaert and Bitondo, 1992). From an agronomic standpoint, the structural degradation indicates a low physical fertility (Mérelle, 1998) likely to increase the risk of soil losses with the selective removal of nutrients and fine elements (clay, silt, organic matter, etc.) essential for soil fertility and quality (Olina Bassala et al., 2008; Quantin, 1992; Rouse et al., 1974). A significant difference is recorded for sand content in Tamounde and Douka-Longo, while the soil sealing index (IB) wasn't significantly different in Douka-Longo and Sabongari (Table 2), with respect-ive values of 12.33% and 10.54 %. Those physical soil properties settings indicate a high risk of erosion. The cohesion of the soil particles is increased along with their resistance to detachment, which reduces the intensity of erosion. However, as the physical soil characteristics contribute to the soil resistance to detachment, the drawback is that it greatly reduces the rate of water infiltration and increases the rate of runoff (Morschel and Fox, 2008). Likewise, the driving crust of these soils might present mechanical resistance to root growth (Fabre and Kockma, 2002; Tremblay-Boeuf, 1995) In Tamounde, soil sealing Index (IB) was significantly different from those of Douka-Longo and Sabongari with an average value of -7.1%. Consequently, this soil had no risk of erosion (IB<1.4%). In terms of fertility, this soil is therefore favorable to good root development (Remy and Marin-Laflèche formula, 1974). These soils also favored water infiltration while maintaining a good water reserve in the soil (Morschel and Fox, 2008).

Soil organic matter (SOM) is a source of carbon for the nutrition and proliferation of soil microorganisms (Chaussod et al., 1986) providing a large part of the phosphorus available for the plants (Bationo et al., 2006). In the soils investigated, (Douka Longo -

2006). In the soils investigated, (Douka Longo -

Tamoundé -Sabongari), the organic matter contents varies between 0.72 to 0.95%, falling within the average value according the classification system of the Land Evaluation (Sys et al., 1993). It should be noted that the organic matter at Douka Longo (0.72 ± 0.14%) and Sabongari (0.77±0.15%) were not significantly different, unlike Tamounde with the significantly highest value (0.95 ± 0.21%). Similar results have been reported by Pallo and Thiombiano (1989) highlighting that the SOM is less than 2% in about 70% of cases in tropical soils. The difference in altitude and the droppings of passing cattle can explain the difference in SOM levels between the sites. Tamoundé is the area with the largest number of livestock. The Forestier index (IF) varied from 0.015 to 0.087 with a mean value of 0.087 ± 0.04 (IF<1.5). Those values reflected a low nutrient reserve and consequently a low chemical fertility (Nyeck et al., 1993; Tematio et al., 2001). This observation corroborated the very low reserve of exchangeable bases (S: 0.58 ± 0.16 to 1.11 ± 0.24 meq/100g) and low CEC observed in all the sites. These soils had an average bulk density of 1.60 ± 0.02 $g.cm^{-3}$. In terms of acidity, pH gives an indication of the acidity of the different soils. The pH influences the availability of nutrients for plants and the biological activity of the soil (Calvet, 2003; Davet; Pierre., 1996). The optimum pH for nutrient availability and biological activity is between 6.5 and 7. Soil pH close to neutral is advantageous for better root absorption of nutrients (Ognalaga et al., 2016; Ondo, 2011). In our studied sites, the soil pHs were acidic, which can be explained by the leaching of cations such as calcium (Biaou et al., 2018). A significant difference between sites was recorded ($p < 0.05$). The most acidic soil was that of Tamounde with a pH value of 4.80 ± 0.09, followed by Douka-Longo (5.18 ± 0.25) and Sabongari (5.51 ± 0.08). The same trend on soil pH variability was obtained

DOI: 10.6092/issn.2281-4485/20147

by Brabant (Brabant et al., 1985) while working on similar soils in North Cameroon.

Fertility parameters equilibriums across sites

According to the FAO textural diagram, the studied soils had sandy texture (Figure 2), with a predominance of the sand fraction of 85.5% on average, characteristics of Arenosols as the main soil group of the area (Tsozué et al., 2020). The silt fraction is low with an average of 6.6%, while the clay fraction has an average of 7.9%. Similar results were obtained by Brabant and Humbel in 1974. From an agronomic point of view, these soils are dry due to the high infiltration rate, poor in nutrients leached trough water migration. However, the capacity of sandy soils to retain nutrients and water can be improved by adding organic matter. According to Dabin's diagram in relation to the soil pH and the total nitrogen content, three classes of fertility were defined. Poor fertility soils were identified in Tamounde with pH between 4.7 and 4.9. Medium fertility at Douka-Longo with pH between 4.8 and 5.5 and good fertility soils in Sabongari with pH between 5.4 and 5.7 (Figure 3). The Kamprath index (m) is used to determine the level of aluminum toxicity. Excess of aluminum leads to a slowdown in the growth of most plant species whose roots atrophy (Kamprath, 1970). The results obtained from our study allowed us to define sites with high aluminum toxicity (m > 20%) at Tamounde (m = 38.6 ± 3.8) and those with low aluminum toxicity (m < 20%) in Douka-Longo (m = 17.7 ± 14.9) and Sabongari (m = 6.1 ± 1.2) (Table 2). This can be explained by the aluminum ions, strongly buffering the soil pH downwards, due to the alteration of weak aluminosilicates (Folkert van Oort, 2022; Jean-Luc et al., 2022; van Oort et al., 2022). The binary diagram of Dabin shows antagonism or synergy between potassium and magnesium in the soil (Figure 5). The K/Mg ratio is not significantly different between Douka-Longo and Sabongari with respective values of 0.30 ± 0.01 and 0.31 ± 0.03. These values translate a balanced absorption of K and Mg, characterizing a positive interaction in the studied sites (0.05 < K/Mg < 0.5). It should be noted that, despite the balanced absorption of the two cations, their content in the soil is very low (K< 0.1 and Mg < 0.5). The potassium deficiency may be due to leaching, which is more important in sandy soils. Tamounde site showeds a significantly higher K/Mg ratio value (0.54 ± 0.13). This ratio value reflects a deficit of Mg supply and excess of K uptake in Tamounde soils with K/Mg > 0.5. It should also be noted that the contents of the two cations (K and Mg) are very low (K < 0.1 meq:100g and Mg < 0.5 meq:100g) (Figure 5). The low value of K and Mg may be due to leaching, given the sandy texture of the soils along with a low CEC and a small proportion of clay. Mg in Tamoundé soils is likely insoluble due to aluminum toxicity (m > 20%). Calcium, like other positive ions (Mg and K), has the role of neutralizing mineral and organic anions and reducing the toxicity of certain elements (such as Aluminum) and consolidating plant cell walls. In the absorbing complex, Ca and Mg play plastic and physiological roles (Demolon, 1932). However, their content is very low in the studied soils with Ca < 2 meq: 100g and Mg < 0.5 meq:100g. Nevertheless, the Ca/Mg ratio reflects an absorbing equilibrium between Ca and Mg as the respective Ca/Mg values were within the range 1 < Ca/Mg < 5 (figure 6). The Ca/Mg ratio shows a significant difference (P < 0.05) between the three sites (Table 2). The content of Ca and Mg is mainly attributed to the similarity of parent material's mineralogy of the sites (Chadwik and Graham, 2000) and its low value is likely induced by leaching and nutrients loss through harvesting without replenishment by adequate fertilizer application. Base saturation (S/CEC) and pH provide precise information on the level of soil acidification (Quemada and Cabrera, 1995). Soil pH is closely related to the amount of bases present in the soil (Meyim, 2000), and the balance between the

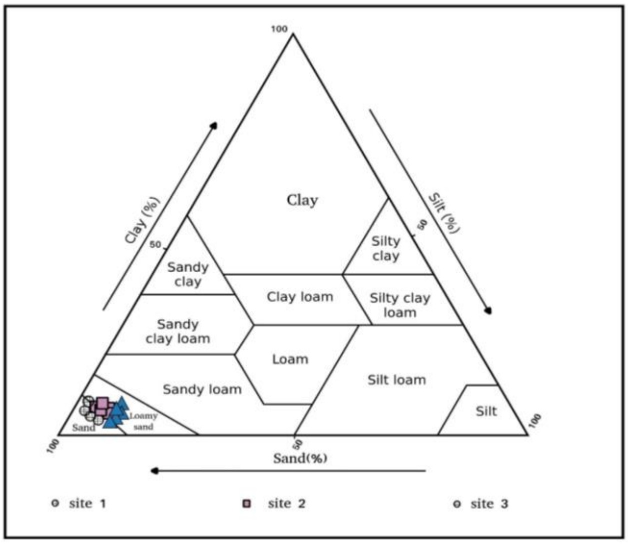

Figure 2: *Soils textural class*

DOI: 10.6092/issn.2281-4485/20147

base saturation and the pH makes it feasible to spot the influence of soil pH on the evolution of exchangeable bases (Fig. 4). Indeed, soils in our study area are grouped into two categories, namely: moderately saturated soils (20 < S/CEC < 50) in Douka-Longo and Tamoundé, and unsaturated soils (S/CEC > 50) in Sabongari. According to Compaoré et al. (2011) and Rhoades et al. (1982), the critical level of P in soil is between 10 and 20 ppm. Following this threshold, phosphorus is a deficient nutrient in the soils investigated, as the values are below 7 ppm, with a non-significant difference between the three sites. Lower P value in the area y might be due to the low soil pH which limits P availability (Nanganoa et al., 2020) .

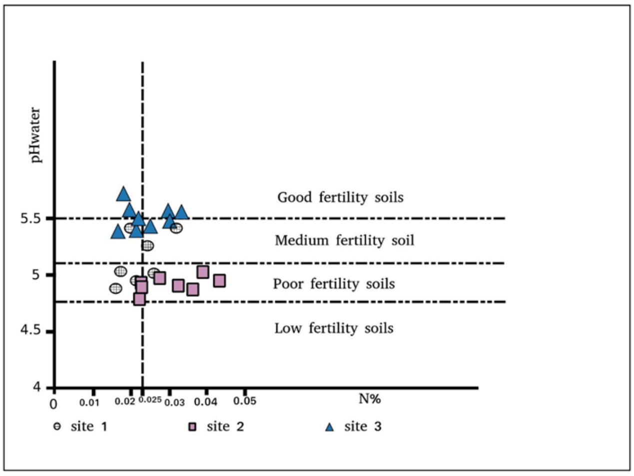

Figure 3. *Soil N-pH equilibrium*

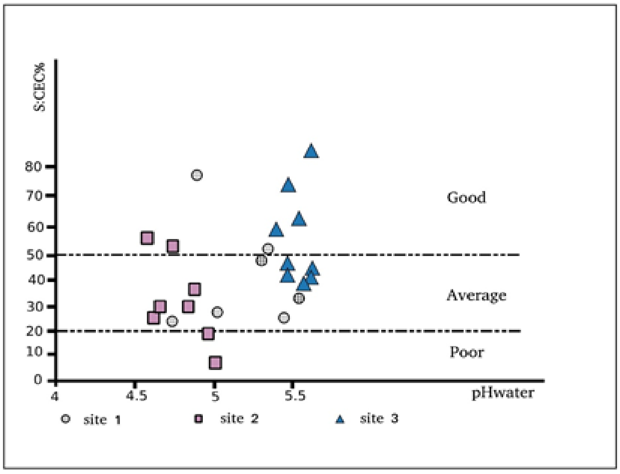

Figure 4. *Soil S:CEC- pH equilibrium*

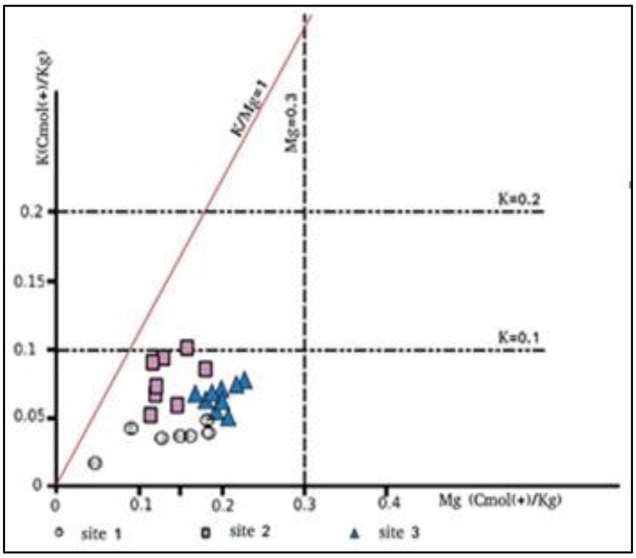

Figure 5. *Soil K-Mg equilibrium*

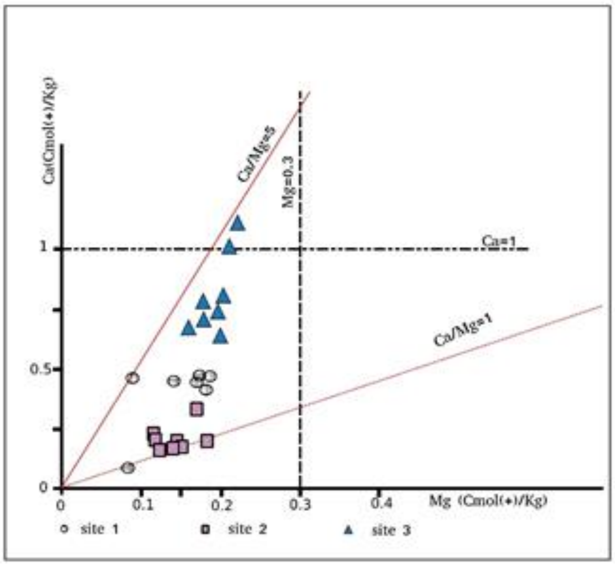

Figure 6. *Soil Ca-Mg equilibrium*

Soil Quality Index (SQI)

The principal component analysis (PCA) enabled us to depict ten essential indicators (OM, pH_w, P, Ca, Mg, K, Al, C/N, CEC, and N), which were applied to compute the SQI. The most appropriate indicators of soil quality were selected by subjecting the values of soil physicochemical properties in table1. The first two principal components explained about 61.1% of the total variation (36.7% by component 1, and 24.46% by component 2. It should be noted that, apart from the available P, K, CEC, and C/N, the other six indicators (Ca, Mg, N, MO, pHw and Al) are well represented because they are closed to the circle border (Fig. 7). There is a strong correlation between Ca, Mg, pHw, OM, available P, total nitrogen, and CEC (Fig. 7) which are the main

DOI: 10.6092/issn.2281-4485/20147

indicators controlling soil quality in the area. The post-hoc test identified the highest SQI at Sabongari (0.4 ± 0.03) followed by Tamounde (0.3 ± 0.014) and the lowest at Douka-Longo (0.25 ± 0.01). The low SQI for these soils indicates poor soil fertility, synonymous with degraded soils. This attest to the re- sults of previous studies (Andrews et al., 2002; Mamouda et al., 2021; Nguemezi et al., 2020; Turan et al., 2019) reporting that soils with low SQI also have low reserve of nutrients and poor fertility. The groundnuts, being leguminous plants, with the capacity to fix their own nitrogen. The groundnuts do not require high levels of nitrogen but high amount of available P. However, numerous studies have shown that nitrogen application has a significant effect, especially before nodulation (Tekulu et al., 2020).

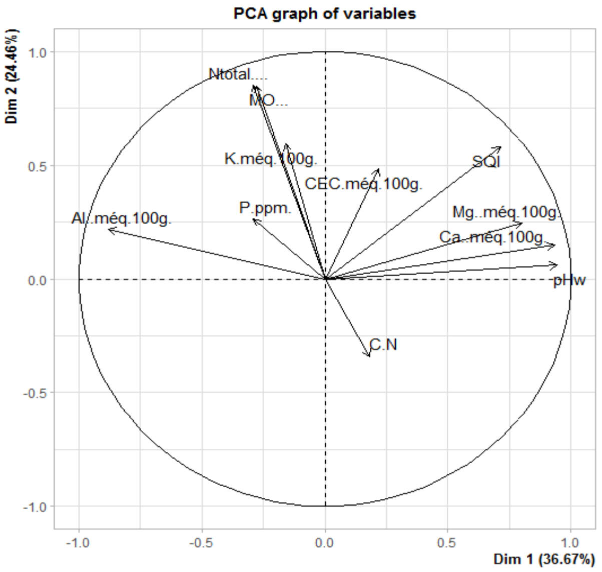

Figure 7. *Variable factor map PCA: principal component analysis; SQI: soil quality index; OM: organic matter; C:N ratio; CEC: Cation exchange capacity; Mg: magnesium; pHw: pH water; Al: Aluminium, P: phosphorous; Ca: calcium; K: potassium.*

Soils fertility status

Statistical analysis of the fertility parameters and the balances between parameters made it possible to assess the current state of fertility of the studied soils. The corresponding soils were grouped into fertility classes according to Quemada and Cabrera (1995) completed by Mamouda et al. (2021) and Nguemezi et al. (2020) with the addition of information on the soil quality index (SQI), Soil sealing index (IB), Forestier index (IF), Soil aggregate stability index (ISS), and the aluminum toxicity (m). Table 3 presents the criteria for the evaluation of soil fertility classes.

Table 3. *Criteria for evaluation of soil fertility classes*

Characteristics	Class I (no limitations)	Class II (average limitation)	Class III (severe limitation)	Class IV (very severe limitations)
OM (%)	>1.38	0.69-1.38	-	< 0.69
N (%)	>0.08	0.045-0.08	0.03-0.045	< 0.03
P (ppm)	>20	10-20	5-10	< 5
K (cmol(+)/kg)	>0.4	0.2-0.4	0.1-0.2	< 0.1
S (cmol(+)/kg)	>10	5-10	2-5	< 2
S/CEC (%)	>60	40-60	15-40	< 15
CEC (cmol(+)kg)	>25	10-25	5-10	< 5
pHw	>5.5	5.1-5.5	4.75-5.1	< 4.75
IB	< 1.4	1.6-1.4	1.8-1.6	>1.8
IF	>1.5	-	-	< 1.5
ISS	>9	7-9	5-7	< 5
m (%)	< 20	20-40	40-60	>60
SQI	0.70-1.00	0.55-0.70	0.40-0.55 [	0-0.40

DOI: 10.6092/issn.2281-4485/20147

The soil fertility class evaluation criteria in table 3 were used to produce table 4. The summary of soil fertility assessment in the Ngong region is presented in table 4. This table shows that the three sites (Douka-Longo; Tamoundé; Sabongari) share common limiting factors: N, P, K, S, CEC, IF, ISS, SQI. Besides these factors, pH is always the limiting factor at site 2 (Tamoundé), which can also be explained by the fact that Ca has the lowest value at Tamounde than at site 1 (Douka-Longo) and site 3 (Sabongari).. In contrast to site 1 (Douka-Longo) and site 3 (Sabongari) where IB is not a limiting factor and belongs to class IV in table 4, IB is not a limiting factor in site 2 (Tamoundé) class I. The results of the fertility assessment of the soils of Douka-Longo; Tamounde; Sabongari all fall under the poor fertility class (class IV), showing soil characteristics having more than one severe limitation. Groundnuts are very tolerant to soil pH; they are grown in soils with pH of 4 to 5 (Schilling, 1991). Groundnut needs a light porous soil that allows good aeration. Phosphorus is the main element needed by groundnuts as it is active during development and maturation. In view of all the soil characteristics of the different sites, and the specificity of groundnuts, the Tamounde site is more suitable for groundnut cultivation, followed by Sabongari site and finally by Douka-Longo site. Amending the soil with organic matter, calcium and potassium will likely contribute to promote the availability P and Mg (Bonzi et al., 2008; Pieri and Christian., 1992) for the plant to enhance fertility and roots development.

Table 4. *Synthesis on the evaluation of soil fertility in the Ngong area*

Sites	OM	m	S	CEC	K	N	P	S/CEC	pH	IB	IF	SQI	ISS	Fertility level	Limiting Factors
	%	%	%	Cmol(+)/kg)		%	ppm	%							
S1	II	I	IV	IV	IV	IV	IV	IV	II	IV	IV	IV	III	mediocre	N,P,K,S,CEC, IB,IF,ISS,SQI
S2	II	III/V	IV	IV	IV	IV	IV	IV	III	I	IV	IV	III	mediocre	N,P,K,S,CEC, IF,ISS,pH,SQI
S3	II	I	IV	IV	IV	IV	IV	IV	I	IV	IV	III	III	mediocre	N,P,K,S,CEC, IB,IF,ISS,SQI

S1: Douka-Longo; S2: Tamoundé; S3: Sabongari

Addressing soil constraints for groundnut production in Ngong

Soils in the studied sites had sandy texture (Figure 2), Sandy soils do not have the capacity to hold enough water and nutrients. The constraints to their cropping reside in their high permeability, their low organic matter content and their low fertility level which are responsible for water and nutrients stresses observed in crops (Basga and Nguetnkam, 2015). Groundnut gives better yield when good cultivars are planted on soils with an optimal soil nutrients management system. If the soil is not properly maintained, they rapidly deplete the soil nutrients reserve (Veeramani and Subrahmaniyan, 2011). The key for optimising groundnut production is to optimise mineral nutrition. Groundnut farmers in the Ngong production basin use very little nutrient fertiliser, resulting in severe mineral nutrient deficiencies due to inadequate and unbalanced nutrient use (Argaw, 2017; Cobo et al., 2011). This nutrient imbalance is one of the main factors responsible for low groundnut yields. Nutrient input optimization will help to restore and increase the soil fertility and improve the groundnut productivity. Proposing solutions based on the living conditions of the people, the environment and the quality of the soil in the study area would be the more reliable option. Nitrogen plays an indispensable role in all cropping systems due to its benefits for various biochemical and physiological processes in the plant (Saghaiesh et al., 2019; Tekulu et al., 2020). Souri et al. (2019) showed that the application of N fertilizer as foliar or soil application has a significant impact on the growth, yield, and quality of many crops, including groundnut. Soil test results from the study area showed a low level of soil nitrogen (0.02 - 0.04%). Improving groundnut yields thus requires the addition of nitrogen. Cow dung and crop residues (groundnut husks, etc.) are available and can be used to produce low-cost organic manure to increase soil nitrogen levels, while also enhancing the soil organic matter content. It is important to note that the application a high dose of N manure (> 20 kg ha^{-1}) inhibits the development of nodules in leguminous plants (Prasad et al., 2010). The results from the study area showed a very low (0.02 to 4.5 ppm) level of soil available phosphorus. Phosphorus plays several roles in the

DOI: 10.6092/issn.2281-4485/20147

functional metabolism of plants (Saghaiesh et al., 2019). This element is also important for groundnut crops, because it is responsible for increasing residual soil nitrogen and is essential for healthy and efficient root growth (Meena and Lal, 2018; Yakubu et al., 2010). It is available in local market in form of triple or double superphosphate. Groundnut performance has been shown to be significantly improved by applying P at 20 - 40 kg ha^{-1} in similar conditions in Nigerian (Yakubu et al., 2010). Potassium is an essential nutrient that is required by plants in relatively high amounts (Nurzyńska-Wierdak et al., 2012). Potassium has been shown to be a key nutrient for growing, rooting and nodulating plants. Soil results indicated that potassium supplementation would be essential for groundnut crops due to deficiency of this element. Application of organo-mineral amendments rich in P, K, Ca, and Mg will promote plant root establishment, improve soil structure and consequently CEC. Groundnuts are sensitive to salinity and not very sensitive to alkaline soils but prefer soils with a pH close to neutral. Soils, which are excessively acidic (pH < 5), may cause manganese or aluminium toxicity. These acidic soils require calcium addition to maintain a pH above 5.5. For the Douka-Longo and Sabongari soils, maintenance liming will only be necessary every 4 years to maintain the pH. Application of lime to correct the low soil pH of Tamounde soils should be done over several consecutive years in small quantities and slowly so as not to block the mineral elements contained in the soil. Since ISS is a limiting physical parameter of the Ngong soils and also plays an important role in groundnut production, it is important to make these soils stable by improving their physical fertility using methods such as covering the soil with crop residues in fields, use of biochar produced from crop residues, all of which will reduce run-off and maintain surface porosity. Possible solutions for restoring low SQI include planting legumes and incorporating woody perennials into cropping systems (El Tahir et al., 2009; Githae et al., 2013; Basga et al., 2018). The *Acacia Senegal* tree is a typical tree that is adapted to sandy soils. The introduction of this tree on farms has contributed to the restoration of soil fertility (it reduces erosion and stabilises the soil) and to the diversification of income sources for farmers. In our study area, soil fertility and groundnut production could be significantly increased by establishing an agro-system with this type of tree (Harmand et al., 2012; Offossou, 2011).

Conclusions

The aim of the present study was to investigate the soil quality and fertility status for groundnut production in Ngong. Fertility attributes and the soil quality index of three sites were considered and assessed, to create a soil database, which supported the soil fertility level assessment and classification, with the aim of having a sustainable and profitable cropping system, likely to improve soil productivity, and thus contributing to the fight against food insecurity. Our study showed that all three sites had poor fertility class, with only one fertility class. These soils showed almost five minimum parameters highly limiting for groundnut production (P, K, S, CEC, IF). This translates into very low values of K, Ca, Mg, pH, OM, available P, total Nitrogen, and CEC. There was also high risk of soil degradation because their ISS < 9% and their fertility index IF < 1.5 were low, which translates into a low reserve of soil nutrients. The soils of the Douka-Longo and Sabongari sites were very susceptible to threshing. Long-term maintenance of soil chemical quality requires better management of fertilization and amendment practices according to land use. For sustainable land management and improving groundnut productivity, the soil quality of the different sites must be considered in order to improve the state of soil fertility for good agricultural development.

Acknowledgements

The data used in this study were collected within the framework of ProSEP (Soil, water and plants project) in Cameroon. The authors express their gratitude and deep appreciation to the German Federal Ministry of Economics and Cooperation for funding (BMZ No. 2014.2472.0). Our thanks are extended to the Federal Institute for Geosciences and Natural Resources (BGR) and the Institute of Agricultural Research for Development (IRAD) of Cameroon for all their multiform support.

References

AGUIEB Z., MESSAI, M. (2015) Valorisation des arachides (Arachis hypogea L.) cultivées à la Wilaya D'El-Oued

AMANI I., TEMGOUA E., AZINWI P., KONDO C. (2022) Utilisation de la légumineuse de couverture Desmodium intortum pour le contrôle de l'érosion hydrique dans les Hautes Terres de l'Ouest Cameroun. Étude et Gestion des Sols, 29:351-363

ANDREWS S.S., KARLEN D.L., MITCHELL, J.P. (2002) A comparison of soil quality indexing methods for vegetable production systems in Northern California. Agricultural Ecosystem Environment. 90:25–45. https://doi.org/10.1016/S0167-8809(01)00174-8.

ARGAW A., (2017) Organic and inorganic fertilizer application enhances the effect of Bradyrhizobium on nodulation and yield of peanut (Arachis hypogea L.) in nutrient depleted and sandy soils of Ethiopia. International. Journal. Recycl. Org. Waste Agric., 6:219–231. https://doi.org/10.1007/s40093-017-0169-3.

BARBIER B., WEBER J., DURY S., HAMADOU O., SEIGNOBOS C. (2003) Savanes africaines : des espaces en mutation, des acteurs face à de nouveaux défis.

BASGA S.D., OUMAROU P.M., BALNA J., ABIB F.C., TSOZUE D., NJIEMOUN A. (2018) Sandy soil fertility restoration and crops yields after conversion of long-term Acacia senegal planted fallows in North Cameroon. African Journal of Agricultural Research 13(40):2154-2162. https://doi.org/10.5897/AJAR 2018. 13283

BASGA S.D., NGUETNKAM J.P. (2015) Fertilizing effect of swelling clay materials on the growth and yield of bean "*Phaseolus vulgaris*" on the sandy ferruginous soils from Mafa Tchéboa (North Cameroun, Central Africa). International Journal of Plant & Soil Science (5)1:10-24. https://doi.org/10.9734/IJPSS/2015/13180

BATIONO A., HARTEMINK A., LUNGO O., NAIMI M., OKOTH P., SMALING E., THIOMBIANO L., (2006) African soils: their productivity and profitability of fertilizer use : background paper for the African Fertilizer Summit 9-13th June 2006, Abuja, Nigeria.

BEERNAERT F., BITONDO D. (1992) Simple and Practical Methods to Evaluate Analytical Data of Soil Profiles. CUDs Dschang Soil Sciences Department, Belgium Cooperation, Dschang. - References - Scientific Research Publishing [WWW Document]. URL https://www.scirp.org/reference/referencespapers.aspx?referenceid=2971495. (accessed 2.8.23).

BEGUIN M., PUMAIN D. (2000) La représentation des données géographiques- Statistique et cartographie, 4e ed. Librairie Eyrolles.

BEVERWIJK A. (1967). Particle size analysis of soils by means of the hydrometer method. Sediment. Geol., 1:403–406. https://doi.org/10.1016/0037-0738(67)90070-X.

BIAOU O.D.B., SAIDOU A., BACHABI F.X., PADONOU G.E., BALOGOUN I. (2018) Effet de l'apport de différents types d'engrais organiques sur la fertilité du sol et la production de la carotte (*Daucus carota* L.) sur sol ferralitique au sud Bénin. Int. J. Biol. Chem. Sci. 11:2315. https://doi.org/10.4314/ijbcs.v11i5.29.

BLAKE G.R., (2015) Bulk density. Methods Soil Anal. Part 1 Phys. Mineral. Prop. Incl. Stat. Meas. Sampl. 374–390.https://doi.org/10.2134/AGRONMONOGR9.1.C30

BONZI M., LOMPO F., DELWENDE I. SEDOGO P. (2008) Influence du mode de gestion de la fertilité des sols sur l'évolution de la matière organique et de l'azote dans les zones agro écologiques du Burkina Faso. Synth. soil, water Nutr. Manag. Res. Volta Basin Chapter 5.

BRABANT P., HUMBEL P.F. (1974) Carte pédologique du Cameroun poli a 1/200.000 office de la recherche scientifique et technique outre-mer centre ORSTOM de Yaoundé.

BRABANT P., GAVAUD M., O.R.S.T.O.M. (Agency : France) (1985) Institute of Agronomic Research (Cameroon). Les sols et les ressources en terres du Nord-Cameroun : (provinces du nord et de l'extrême-nord). Edition de l'ORSTOM.

BREJDA J.J., MOORMAN T.B., KARLEN D.L., DAO T.H. (2000) Identification of regional soil quality factors and indicators : I. Central and Southern High Plains. Soil Sci. Soc. Am. J. 64: 2115–2124. https://doi.org/10.2136/SSSAJ2000.6462115X.

BUONDONNO A., RASHAD A.A., COPPOLA E. (1995) Comparing tests for soil fertility. II. The hydrogen peroxide/sulfuric acid treatment as an alternative to the copper/selenium catalyzed digestion process for routine determination of soil nitrogen-Kjeldahl https://agris.fao.org/agris-search/search.do?recordID=US9555112.

CALVET R., (2003) Le sol Propriétés et fonctions. Tome 2 Phénomènes physiques et chimiques. - References - Scientific Research Publishing Appl. Agron. Environ mentales. Fr. Agric. Ed. 511.

CHADWIK O.A., GRAHAM R.C. (2000) Pedogenic Processes. CRC Handb. Soil Sciences.

CHAUSSOD R., NICOLARDOT B., CATROUX G. (1986). Mesure en routine de la biomasse microbienne des sols par la méthode de fumigation au chloroforme. Sci. du sol 201–211.

COBO J.G., DERCON G., CADISCH G. (2011). Nutrient balances in African land use systems across different spatial scales : a review of 50 approaches , challenges and progress 51 52.

COMPAORÉ E., FROSSARD E., SINAJ S., FARDEAU J.C., Morel, J.L. (2011). Influence of Land-Use Management on Isotopically Exchangeable Phosphate in Soils from Burkina Faso, 201-223. http://dx.doi.org/10.1081/CSS-120017426. 201–223

DABIN B. (1961) Les facteurs de la fertilité des sols des régions tropicales en culture irriguée. Bull. Assoc. française d'Etude du Sol 108–130.

DAVET P. (1996) Vie microbienne du sol et production végétale, Librairie Quae : des livres au coeur des sciences.

DAY P.R. (2015) Particle Fractionation and Particle-Size Analysis. Methods Soil Anal. Part 1 Phys. Mineral. Prop. Incl. Stat. Meas. Sampl. 545–567. https://doi.org/10.2134/AGRONMONOGR9.1.C43

DE PAUW E. (2019) Projet Ressources du Sol et du Sous-sol des Régions du Nord et du Sud-Ouest Project on Soil and Subsoil Resources of North and South-West Regions Mission report follow-up workshop-nkolbisson, 12-16 NOVEMBER 2019.

DEMOLON A. (1932) La Dynamique du sol. J. d'agriculture Tradit. Bot. Appliquée, 12:934–940. https://doi.org/10.3406/JATBA.1932.5173.

EL TAHIR B.A., AHMED D.M., ARDÖ J., GAAFAR A.M., SALIH A.A. (2009) Changes in soil properties following conversion of Acacia senegal plantation to other land management systems in North Kordofan State, Sudan. J. Arid Environ. 73:499–505. https://doi.org/10.1016/J.JARIDENV.2008.11.007.

EMERSON R.M. (1976) Social Exchange Theory. Annu. Rev. Sociol., 2:335–362. https://doi.org/10.1146/ANNUREV.SO.02. 080176.002003.

FABRE B., KOCKMA F., (2002). La pratique du chaulage : Conseil au niveau de l'exploitation

FOLKERT VAN OORT. (2022). Les Mots de l'agronomie.

FONCEKA D. (2010) Elargissement de la base génétique de l'arachide cultivée (Arachis hypogaea) : applications pour la construction de populations, l'identification de QTL, et l'amélioration de l'espèce cultivée.

FAO - Food and Agriculture Organization of the United Nations (2006) World reference base for soil resources, 2006 : a framework for international classification, correlation and communication. Food and Agriculture Organization of the United Nations.

FAO - Food and Agriculture Organization of the United Nations (2014) World reference base for soil resources 2014 : international soil classification system for naming soils and creating legends for soil maps. FAO.

GITHAE E.W., GACHENE C.K.K., NJOKA J.T., OMONDI S.F. (2013) Nitrogen Fixation by Natural Populations of Acacia Senegal in the Drylands of Kenya Using 15N Natural Abundance. Arid L. Res. Manag., 27: 327–336.https://doi.org/10.1080/15324982.2013.784377.

GOBAT J.M., ARAGNO M., MATTHEY W. (2003) Le sol vivant : bases de pédologie, biologie des sols. Presses polytechniques et universitaires romandes.

GRIEL A.E., EISSENSTAT B., JUTURU V., HSIEH G., KRIS-ETHERTON P.M. (2004). Improved Diet Quality with Peanut Consumption. J. Am. Coll. Nutr. 23, 660–668.

GUERRIEN MARC. (2003). L'intérêt de l'analyse en composantes principales (ACP) pour la recherche en sciences sociales. http://journals.openedition.org/cal 181–192. https://doi.org/10.4000/CAL.7364.

HACHIM K.N., (2020). Effet des rhizobia et des champignons mycorhiziens sur la croissance, le rendement et la qualité nutritionnelle de deux variétés d ' arachides (Arachis hypogaea L .) cultivées

HAMASSELBE A., (2008). La revalorisation de la filière arachide dans la zone soudano-sahélienne du Nord Cameroun.

HAMIDOU F., HAROU A., ACHIROU B., HALILOU O., BAKASSO Y., (2018). Fixation de l'azote chez l'arachide et le niébé en conditions de sécheresse pour l'amélioration de la productivité au Sahel. TROPICULTURA 36, 63–79.

HARMAND J., NTOUPKA M., MATHIEU B., NJITI C.F., TAPSOU J.-M., BOIS J.C., THALER P., PELTIER R., (2012). Gum arabic production in Acacia senegal plantations in the Sudanian zone of Cameroon: Effects of climate, soil, tapping date and tree provenance. Bois Forets Des Trop.

HEANES D.L. (2008). Determination of total organic-C in soils by an improved chromic acid digestion and spectrophotometric procedure. http://dx.doi.org/10.1080/00103628409367551. 15, 1191–1213.

HUBERT B. (2010) L'agronomie, science de l'agriculture Mouv. Soc. - Mouv. SOC 233, 143–157. https://doi.org/10.2307/40959669.

INGRAM J.S.I., ANDERSON J.M. (1993). Tropical soil biology and fertility: a handbook of methods. CAB International.

INS - Institut National de Statistiques (2017) Annuai-re_statistique_du_Cameroun_2017.

IUSS Working Group WRB. 2022. World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps. 4th edition. International Union of Soil Sciences (IUSS), Vienna, Austria.

FORESTIER J. (1960). Fertilité des sols des caféières en république centrafricaine.

JEAN-LUC J., GUILHEM B., ARY B., CHRISTIAN F., DANIEL T., FOLKERT VAN OORT. (2022). Capacité d'échange cationique du sol. Les Mots l'agronomie.

DOI: 10.6092/issn.2281-4485/20147

KAMDEM T.A.G., LOMBEKO O., VICTORINE T., FONCHA F., CHATUEL C.G., LEH N.M., BONSIYSI B.I., NCHINDA P.V., VENASIUS L. (2020). Response of Soybean (*Glycine max* L. Merr .) to Application of Poultry manure and Mineral fertilizers in the Agro-ecological Zone III of Cameroon. Int. J. Progress. Sci. Technol. 42–47. http://dx.doi.org/10.52155/ijpsat.v19.2. 1660.

KAMPRATH E.J., 1970. Exchangeable Aluminum As a Criterion for Liming Leached Mineral Soils1. Soil Sci. Soc. Am. J. 34:252–254. https://doi.org/10.2136/SSSAJ1970.03615995003400020022X.

LAWRENCE N.T., NJUKENG J.N., NGOSONG C., ATACHE S.K.E., YINDA G.S., EBONLO J.N., NGONG J.N., NGOME F.A. (2019) Short-term benefits of grain legume fallow systems on soil fertility and farmers' livelihood in the humid forest zone of Cameroon, Int. J. Sustain. Agric. Res. 6(4):213-223. https://doi.org/10.18488/journal.70.2019.64.213.223.

LAWRENCE N.T., NGOME F.A., SUH C., BASGA S.D. (2020) Assessing Soil Nutrients Variability and Adequacy for the Cultivation of Maize, Cassava, and Sorghum in Selected Agroecological Zones of Cameroon International Journal of Agronomy. 2020. https://doi.org/10.1155/2020/8887318.

LIX L.M., KESELMAN J.C., KESELMAN H.J. (1996) Consequences of Assumption Violations Revisited: A Quantitative Review of Alternatives to the One-Way Analysis of Variance "F" Test. Rev. Educ. Res. 66, 579. https://doi.org/10.2307/1170654.

MAMOUDA N., OBEN T.F., MELI L., RAOUL G., PALMER Y.B. (2021) This content is available online at AESA Archives of Agriculture and Environmental Science Journal homepage: Determination of soil fertility constraints in two paddy soils of the western highland zone of Cameroon Kfuban. Agric. Environ. Sci. Acad.

MARTIN D. (1979) Fertilité chimique des sols d'une Ferme du Congo.

MARTIN D., SIEFFERMANN G. (1966) Le département du mungo (Ouest-Cameroun) Étude des sols et de leur utilisation.

MATHURIN M., MICHEL T., ABDOULAYE A.A., (2003) Maintien ou amélioration du potentiel productif des sols en région soudano-sahélienne du Nord-Cameroun. HAL 11.

MEENA R.S., LAL R. (2018) Legumes and Sustainable Use of Soils, in: Meena, R.S., Das, A., Yadav, G.S., Lal, R. (Eds.), Legumes for Soil Health and Sustainable Management. Springer Singapore, Singapore, 1–31. https://doi.org/10.1007/978-981-13-0253-4_1.

MÉRELLE F., (1998). L'analyse de terre aujourd'hui, Groupe d'études méthodologiques pour l'analyse des sols (France). FR/GEMAS.

MEYIM D. (2000) Effet des diverses jachères sur l'évolution de la fertilité d'un sol ferralitique des environs de Yaoundé (Cameroun). Mémoire DEA Faculté des Sciences Université Yaoundé I.

MORSCHEL, J., FOX D. (2008) Une méthode de cartographie du risque érosif : application aux collines du Terrefort lauragais

MURPHY J., RILEY J.P. (1962) A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 27, 31–36. https://doi.org/10.1016/S0003-2670(00)88444-5

NGO-MBOGBA M., YEMEFACK M., NYECK B. (2015) Assessing soil quality under different land cover types within shifting agriculture in South Cameroon. Soil Tillage Res. 150:124–131. https://doi.org/10.1016/j. still. 2015.01.007.

NGUEMEZI C., TEMATIO P., YEMEFACK M., TSOZUE D., SILATSA T.B.F. (2020) Soil quality and soil fertility status in major soil groups at the Tombel area, South-West Cameroon. Heliyon 6. https://doi.org/10.1016/j.heliyon.2020.e03432.

NGUEMHE S.C.., ETOUNA J., HAKDAOUI M. (2014) Apport de l'OT et du SIG à la cartographie des zones à risque d'érosion hydrique dans le bassin versant productif de Sanguéré, Nord-Cameroun, Afrique Centrale. Int. J. Innov. Appl. Stud. Vol. 9, 449–479.

NURZYŃSKA-WIERDAK R., DZIDA K., ROŻEK E., JAROSZ Z. (2012) Effects of nitrogen and potassium fertilization on growth, yield and chemical composition of garden rocket. Acta Sci. Pol. Cultus 11, 289–300.

NYECK B., BILONG P., ENO B.S.M., VOLKOFF B. (1993) Séquence d'évolution de sols sur granite dans le sud du Cameroun : cas des sols de Zoetele. Annales de la Faculté des Sciences.

NYECK B., NGO MBOGBA M., NJILAH I., YEMEFACK M., BILONG P. (2018) Contributions of soil chemical and physical properties in the dynamics of soil quality in the southern Cameroon plateau shifting agricultural. Environ Science International Journal of Biological Chemical Sciences. https://doi.org/0.4314/ijbcs.v12i2.32.

OFFOSSOU K. (2011) Remise en culture des jachères enrichies à Acacia senegal au Nord-Cameroun : Productions forestière et agricole, et perceptions paysannes.

OGNALAGA M., ODJOGUI P.I.O., LEKAMBOU J.M., POLIGUI R.N. (2016). Effet des écumes de canne à sucre, de la poudre et du compost à base de *Chromolaena odorata* (L.) King R.M. & H.E. Rob sur la croissance de l'oseille de Guinée (*Hibiscus sabdariffa* L.). Int. J. Biol. Chem. Sci. 9, 2507. https://doi.org/10.4314/ijbcs.v9i5.22.

OLINA J.-P., M'BIANDOUN M., EKORONG J.A., ASFOM P., 2008. Evolution de la fertilité des sols dans un système cotonnier-céréales au Nord Cameroun : diagnostic et perspectives, TROPICULTURA.

ONDO J.A., (2011). Vulnérabilité des sols maraîchers du Gabon (région de Libreville) : acidification et mobilité des éléments métalliques Effects of agricultural practices on properties and metal content in urban garden soils in a tropical metropolitan area View project Metal Accumulation in Amaranthus cruenrus Cultivated on Different Systems of Tropical Urban Gardens View project. https://doi.org/10.13140/RG.2.1.4841.2882.

PALLO F., THIOMBIANO L. (1989). Les sols ferrugineux tropicaux lessivés à concrétions du Burkina Faso : caractéristiques et contraintes pour l'utilisation agricole.

PARTEY S.T., QUASHIE-SAM S.J., THEVATHASAN N. V., GORDON A.M. (2011). Decomposition and nutrient release patterns of the leaf biomass of the wild sunflower (Tithonia diversifolia): a comparative study with four leguminous agroforestry species. Agrofor. Syst. 81, 123–134. https://doi.org/10.1007/S10457-010-9360-5.

PIERI C., CHRISTIAN J. M. G. (1992). Fertility of Soils: A Future for Farming in the West African Savannah. Springer Series in Physical Environment 10. https://doi.org/10.1007/978-3-642-84320-4.

POGGIO L., DESOUSA L.M., BATJES N.H., HEUVELINK G.B.M., KEMPEN B., RIBEIRO,E., ROSSITER D (2021) Soilgrids 2.0: producing soil information for the globe with quantified spatial uncertainty. Soil, 7:217-240. https://doi.org/10.5194/soil-7-217-2021

PRASAD P.V. V, KAKANI V.G., UPADHYAYA H.D. (2010). Growth and production of groundnut.

QUANTIN, P. (1992) Les sols de l'archipel volcanique des Nouvelles-Hébrides (VANUATU). Etude de la pédogenèse initiale en milieu tropical. Strasbourg .

QUEMADA M., CABRERA M.L. (1995). CERES-N Model Predictions of Nitrogen Mineralized from Cover Crop Residues. Soil Sci. Soc. Am. J. 59, 1059–1065. https://doi.org/10.2136/sssaj1995.03615995005900040015x.

RHOADES J.D., MILLER R.M., KEENEY D.R. (1982). Soil Testing., Methods of Soil Analysis., Part 2, 2nd Edition. ed, Soc. Agron, Madison.

ROLAND M. (1986). L'expérience de L'ORSTOM dans le domaine de la fertilité et de l'exploitation des sols tropicaux.

ROUSE J.W., HAAS R.H., SCHELL J.A., DEERING D.W. (1974). Monitoring Vegetation Systems in the Great Plains with ERTS. 3rd , 1:48-62. Earth Resour. Technol. Satell. URL https://www.scirp.org/reference/ReferencesPapers.aspx.

SAGHAIESH S.P., SOURI M.K., MOGHADDAM M.H.Y. (2019) Characterization of nutrients uptake and enzymes activity in Khatouni melon (Cucumis melo var. inodorus) seedlings under different concentrations of nitrogen, potassium and phosphorus of nutrient solution. Journal Plant Nutrition 42: 178–185. https://doi.org/10.1080/01904167.2018.1551491

SCHILLING R. (1991) L'arachide dans les zones de savanes du Cameroun-Nord.

SCHWOERER P. (1965) Carte Géologique de Reconnaissance à L'Echelle 1/500000 Notice Explicative sur la Carte Garoua-Est. Dir. des Mines la Géologie du Cameroun. Yaoundé.

SDN 30 (2020) Stratégie Nationale de Développement 2020-2030.

SERAPHIN B., BOUROU S., ISSA A., NOE W. (2015) Évaluation agronomique de cinq cultivars d'arachide (*Arachis hypogeae* L.) introduits dans la région du Nord Cameroun. J. Appl. Biosci. 89: 8311. https://doi. org/10.4314/jab.v89i1.5

SOURI M.K., NAIJI M.R., KIANMEHR M.H. (2019) Nitrogen release dynamics of a slow release urea pellet and its effect on growth, yield, and nutrient uptake of sweet basil (Ocimum basilicum L.). J. Plant Nutr. 42:604–614. https://doi.org/10.1080/01904167.2019.1568460

SYS C., VAN R.E., BEERNAERT F. (1993) Land Evaluation.

TEKULU K., TAYE G., ASSEFA D. (2020) Effect of starter nitrogen and phosphorus fertilizer rates on yield and yield components, grain protein content of groundnut (Arachis Hypogaea L.) and residual soil nitrogen content in a semiarid north Ethiopia. Heliyon 6. https://doi.org/10.1016/j.heliyon.2020.e05101.

TEMATIO P., NYAMA A.B., KENGNI L., BITOM D., (2001) Influence de la mise en culture sur la fertilité des sols en région forestière tropicale humide du Sud Cameroun.

TREMBLAY-BOEUF, V. (1995) Effets des contraintes mécaniques sur l'exsudation racinaire du maïs. http://www.theses.fr.

DOI: 10.6092/issn.2281-4485/20147

TSOZUE D., NGHONDA J.P., BASGA S..D., TEMATIO P. (2018) Changes in soil properties and soil organic carbon stocks along an elevation gradient at Mount Bamboutos, Central Africa of rainfall variability on crop cultivation calendar in western Highlands in Cameroon View project Soil fertility and capability classification in Cameroon View project Changes in soil properties and soil organic carbon stocks along an elevation gradient at Mount Bambouto, Central Africa. Catena 175, 251–262. https://doi.org/10.1016/j.catena.2018.12.028175.

TURAN İ.D., DENGIZ O., ÖZKAN B. (2019) Spatial assessment and mapping of soil quality index for desertification in the semi-arid terrestrial ecosystem using MCDM in interval type-2 fuzzy environment. Comput. Electron. Agric. 164, 104933. https://doi.org/10.1016/J.COMPAG.2019.104933.

VAN OORT F., PARADELO R., BAIZE D., CHENU C., DELARUE G., GUÉRIN A., PROIX N. (2022) Can long-term fertilization accelerate pedogenesis Depicting soil processes boosted by annual NPK-inputs since 1928 on bare loess Luvisol (INRAE-Versailles). Geoderma 416. https://doi.org/10.1016/J.GEODERMA.2022.115808.

VEERAMANI P., SUBRAHMANIYAN K. (2011) Nutrient management for sustainable groundnut productivity in India- a review. International Journal of Engineering Science Technology. 3:8138–8153.

YAKUBU H., KWARI J., SANDABE M. (2010) Effect of Phosphorus Fertilizer on Nitrogen Fixation by Some Grain Legume Varieties in Sudano – Sahelian Zone of North Eastern Nigeria. Niger. J. Basic Appl. Sci. 18:19–26. https://doi.org/10.4314/njbas.v18i1.56837.

YEMEFACK M., JETTEN V.G., ROSSITER D.G. (2006). Developing a minimum data set for characterizing soil dynamics in shifting cultivation systems. Soil Tillage Res. 86:84–98. https://doi.org/10.1016/J.STILL.2005.02.017.

ZHANG H., SCHRODER J.L., FUHRMAN J.K., BASTA N.T., STORM D.E., PAYTON M.E. (2005) Path and Multiple Regression Analyses of Phosphorus Sorption Capacity Soil Science Soc. Am. J. 69:96. https://doi.org/10.2136/sssaj2005.0096dup.