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Research Article
Identification of Soil Management Factors for Sustainable Oil Palm (*Elaeis guineensis* Jacq.) Production in Coastal Plains of Southwest Cameroon

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Abstract
Background and Objective: Efficient soil fertility management is imperative in achieving sustainable oil palm production. This study was conducted to identify soil management factors in view of optimizing oil palm production in coastal lowlands of Southwest Cameroon. **Materials and Methods:** Forty two surface (0-30 cm) and subsurface (30-60 cm) soils under oil palm plantations were analyzed using standard laboratory methods and soil data was subjected to descriptive statistics, principal component analysis (PCA) and cluster analysis. **Results:** In both surface and subsurface soils, >80% of soil properties were highly variable (Coefficient of variation >35%). Principal Component analysis yielded four management factors with surface soils and 5 factors with subsurface soils, accounting for 81.1 and 83.6% of the variation in soil properties, respectively. Based on the principal components derived, the main soil characteristics necessitating management vis-à-vis oil palm growth were base status (exchangeable K^+ and Mg^{2+}, CEC and base saturation), soil acidity (pH-H_2O), soil organic matter and available P content. **Conclusion:** Considering the fertility status of the soils, recommended management practices most likely to increase and sustain oil palm production in lowland plains of Southwest Cameroon include adequate use of chemical fertilizers (N, P, K, Mg), adapted legume cover crops for improving on soil N content and the addition of soil organic matter through proper residue management.

Key words: Oil palm, coastal plain soils, factor analysis, soil fertility management, principal component analysis, cluster analysis

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Soil is a critical component of sustainable agriculture because it is the original source of plant nutrients which help to enhance crop production[1,2]. Sustainable agriculture has been widely recognized as a potentially viable means of meeting the future food demands of an ever-growing world population[3] and a precondition for achieving sustainable agriculture and increased crop yields is the proper management of soil fertility. Effective soil resource management, which is an important and intrinsic aspect of sustainable agriculture, is needed to overcome limitations to productivity while maintaining or enhancing environmental quality[3]. Notwithstanding, effective soil resource management is still a major problem in many countries, especially in sub-Saharan African countries. One of the problems limiting effective and efficient soil fertility management for optimal crop production is lack of information on soil fertility status and soil management factors with respect to a specific crop.

The coastal plains of southwest Cameroon harbor most of the oil palm plantations of the country, which serve as an important income-generating crop for many agro-industries and smallholder farmers. A detailed soil survey in the apparently equally uniform soil pattern (the Tiko plain) revealed a wide variety in soil types[4] (Orthic Ferralsols, Ferralic Cambisols, Gleyic Cambisols, Ferric Acrisols and Humic Acrisols). With respect to studies on the detailed assessment of soil variability in the Coastal plains of Southwest Cameroon, very little information is available. Such information is very important for ecological intensification[5], given that parts of the coastal lowlands of southwest Cameroon are home to very rich and unique biodiversity. It appears there is actually no single generalizable model of ecological intensification due to variation in soil properties and any generalization in practice would be contrary to the context-specific and ecosystem-based approaches of ecological intensification[6]. For example, in a complex topographic landscape such as highlands, models of ecological intensification such as organic agriculture, climate smart agriculture, conservation agriculture and agroforestry, are practiced[7], but these practices definitely differ in their implementation depending on the influence of landscape attributes[8]. In rather homogenous landscapes such as lowland plains, one of the best practices involves detailed soil fertility investigations and the efficient use of plant nutrients such as NPK fertilizers[9,10]. Such investigations must be complemented with information on the variability of soil properties across the landscape. The diversity in soil properties alongside soil quality factors, as a strategy for sustainable management and production has been overlooked. Soil quality indicators are defined as measurable soil attributes that reveal the soil productivity response or soil-environment functionality that are used to know whether soil quality is improving, stagnant or declining[11]. Many methods have been used to identify soil quality factors necessitating management attention, including the use of soil quality indices. These indices represent the cumulative effects of different soil properties as an index from the role of each indicator in soil quality[11]. The assessment of soil quality indicators provides vital information necessary for improving crop yield[12] and a common technique that has been used in such studies is factor analysis of soil properties[11,12]. The objective of this study was to identify soil management factors in Coastal lowland plains of southwest Cameroon that can guide on site-specific soil management for sustainable oil palm intensification, with focus on the use of factor analysis of routinely measured soil properties influencing oil palm productivity.

MATERIALS AND METHODS

Study area: The study was carried out in the Department of Soil Science, Laboratory of Soil Analysis and Environmental Chemistry (LASAEC) in the University of Dschang. Field study was conducted from July, 2017 to October, 2019 in the Coastal plains of Southwest Cameroon. The study area has the equatorial climate, precisely the Cameroon type which is quite hot and humid, characterized by the existence of 2 distinct seasons-one wet (rainy) season (running from March to October) and a comparatively short dry season (running from November to February). The dominant type is the mountain type where rainfall is very high with >2000 mm annual rainfall. Average temperatures are high at the low altitude areas, ranging from 23-26°C, as well as high atmospheric humidity (>80%). Some areas also experience the Maritime Cameroon climate type with higher amounts of rainfall (>5000 mm). The reference soil groups in the area consist of Andosols, Leptosols, Cambisols, Nitisols and Acrisols[13]. These soil groups correspond to the soil orders Andisols, Entisols, Inceptisols, Alfisols, Ultisols and Oxisols, respectively, following the U.S. Soil Taxonomy. Soil parent material within the area is mainly sedimentary and volcanic in nature and is varied, including basaltic lavas, recent alluvial deposits, volcanic ash deposits and granites.

Table 1: Critical soil fertility levels for oil palm growth

Soil properties	Very low	Low	Moderate	High	Very high
pH-H_2O	<3.50	3.5-4.0	4.0-4.2	4.2-5.5	>5.50
Organic C (%)	<0.80	0.8-1.2	1.2-1.5	1.5-2.5	>2.50
Total N (%)	0.08	0.08-0.12	0.12-0.15	0.15-0.25	>0.25
Available P (ppm)	<10.00	10-25	25-40	40-60	>60.00
Exchangeable K^+ (meq/100 g)	<0.08	0.08-0.2	0.2-0.25	0.25-0.3	>0.30
Exchangeable Mg^{2+} (meq/100 g)	<0.08	0.08-0.2	0.2-0.25	0.25-0.3	>0.30
CEC (meq/100 g)	<6.00	6-12	12-15	15-18	>18.00

Source: Goh and Chew[21] and Goh and Po[22]

Soil sampling and methods of soil analysis: Forty two surface (0-30 cm) and subsurface (30-60 cm) soils supporting oil palms within the coastal lowland plains of Southwest Cameroon were collected randomly and used for this study. Soil samples from the field were air-dried at room temperature, crushed and sieved through a 2 mm sieve. The <2 mm soil fraction was analyzed for physical and chemical properties. Particle size analysis was done using the hydrometer method as described by Bouyoucos[14] after dispersion of 50 g of soil with 2.5 N sodium hexametaphosphate solution. Chemical properties were determined following standard procedures[15]. Soil organic carbon content was determined by the Walkley-Black wet combustion method by oxidation with potassium dichromate and titration with iron (II) sulphate. Soil pH was measured in a 1:2.5 soil:solution ratio in 1N KCl (pH-KCl) and distilled water (pH-H_2O). Total N and available phosphorous were determined by the Kjeldahl wet digestion and the Bray II methods, respectively. Exchangeable bases (Na^+, K^+, Ca^{2+}, Mg^{2+}) were determined following the Schollenberger method by leaching 2.5 g of soil with 100 mL of a 1 M ammonium acetate solution buffered at pH 7. The concentrations of Na^+ and K^+ ions in the extract were obtained by flame photometry and those of Ca^{2+} and Mg^{2+} were estimated by complexometric titration using a 0.002 M Na_2-EDTA solution. Cation exchange capacity (CEC) was estimated by leaching 2.5 g of soil with 100 mL of a 1M ammonium acetate solution buffered at pH 7 and then with 1 N KCl and the displaced NH_4^+ ions determined by distillation and titration with 0.01 N sulphuric acid.

Assessment of soil fertility status: To assess the fertility status of the soils, limits for various soil properties were set as shown in Table 1 and used as criteria for rating the fertility status of the soils in the different sites. Samples from each set were ranked into 5 classes: Very poor fertility (very low), poor fertility (low), marginal fertility (medium), good fertility (high) or very good (very high) status.

Statistical analysis: Statistical variability in soil properties was evaluated using the coefficient of variation (CV), given by the equation[16]:

$$CV = \frac{\text{Standard deviation}}{\text{Mean}} \times 100 \quad (1)$$

Based on the values of CV, soil properties having CV values <15% were considered as least variable, those with CV between 15 and 35% were grouped as moderately variable and those with CV values >35% indicated high variability[16].

Identification of factors causing soil variability: In order to identify and explain factors accounting for the variation in soil properties, factor analysis was carried out through dimension reduction. The method of extraction used was principal component analysis (PCA) based on eigenvalues >1 and was performed on surface and subsurface soil properties. Principal components were derived and interpreted following standard procedures[17,18].

Hierarchical clustering analysis was performed to complement principal component analysis for clustering of soil properties. Cluster analysis is a method which can be applied to multidimensional data sets in order to study similarities of objects (soil samples in this case) in the variables' space (soil parameters) or similarities of variables in the objects' space[19,20].

RESULTS

Variability of soil properties and correlation among soil properties: Descriptive statistics and coefficients of variation (CV) of the various soil properties are shown in Table 2 for surface and subsurface soils. Sand content was dominant in both surface and subsurface soils followed by clay content and lastly silt. Values of soil pH indicated that all the soils ranged from acidic to slightly acidic. Organic carbon contents ranged

Table 2: Descriptive statistics and coefficient of variation of soil properties (n = 42)

Properties	Minimum	Maximum	Mean±SE	Median	Std. Dev.	CV (%)	Skewness±SE	Kurtosis±SE
Surface soils (0-30 cm)								
Sand (%)	2.17	95.00	49.12±4.32	44.14	28.02	57.04	-0.02±0.37	-1.30±0.71
Silt (%)	1.00	50.20	18.06±2.01	18.75	13.05	72.26	0.52±0.37	-0.56±0.71
Clay (%)	3.20	76.60	32.41±2.89	29.33	18.74	57.82	0.73±0.37	-0.04±0.71
pH-H_2O	3.76	6.25	5.02±0.07	4.98	0.51	10.16	0.52±0.37	0.81±0.71
pH-KCl	3.51	5.60	4.09±0.07	3.98	0.45	11.00	1.92±0.37	3.92±0.71
Ca^{2+} (meq/100 g)	0.00	10.78	3.12±0.43	2.02	2.83	90.71	1.04±0.37	0.18±0.71
Mg^{2+} (meq/100 g)	0.00	9.13	2.45±0.33	2.04	2.16	88.16	1.19±0.37	1.22±0.71
Na^+ (meq/100 g)	0.00	0.28	0.08±0.01	0.07	0.07	87.50	0.85±0.37	-0.22±0.71
K^+ (meq/100 g)	0.04	1.96	0.36±0.06	0.22	0.42	116.67	2.79±0.37	8.33±0.71
Σ bases (meq/100 g)	0.10	17.78	5.83±0.69	4.58	4.50	77.19	0.83±0.37	0.13±0.71
CEC (meq/100 g)	2.97	57.18	15.41±1.59	13.22	10.31	66.90	2.09±0.37	6.31±0.71
BS (%)	2.00	82.80	38.78±3.73	32.75	23.92	61.68	0.29±0.37	-1.06±0.71
OC (g kg^{-1})	3.70	45.89	13.58±1.20	11.55	7.78	57.29	2.26±0.37	7.07±0.71
TN (g kg^{-1})	0.57	6.25	1.62±0.14	1.41	0.96	59.26	3.04±0.37	12.51±0.71
C/N	4.89	14.56	8.71±0.34	8.34	2.20	25.26	0.87±0.37	0.78±0.71
Available P (mg kg^{-1})	0.57	40.00	9.31±1.41	5.43	8.48	91.08	1.69±0.37	3.43±0.71
Subsurface soils (30-60 cm)								
Sand (%)	2.00	94.33	47.86±4.19	45.85	27.20	56.83	0.10±0.37	-1.16±0.71
Silt (%)	1.00	57.60	16.73±1.84	14.44	11.98	71.59	1.06±0.37	1.77±0.71
Clay (%)	3.47	78.00	33.97±3.16	34.07	20.49	60.31	0.41±0.37	-0.58±0.71
pH-H_2O	3.80	6.38	4.99±0.11	5.00	0.70	14.00	-2.06±0.37	10.09±0.71
pH-KCl	3.64	5.42	3.99±0.09	3.90	0.60	15.03	-0.49±0.37	5.87±0.71
Ca^{2+} (meq/100 g)	0.00	9.28	2.21±0.35	1.42	2.28	103.08	1.51±0.37	1.82±0.71
Mg^{2+} (meq/100 g)	0.00	10.38	2.29±0.32	1.76	2.12	92.38	1.71±0.37	4.11±0.71
Na^+ (meq/100 g)	0.00	0.29	0.07±0.01	0.05	0.08	107.38	0.92±0.37	-0.17±0.71
K^+ (meq/100 g)	0.00	0.88	0.24±0.03	0.19	0.22	89.98	1.91±0.37	2.98±0.71
Σ bases (meq/100 g)	0.10	17.54	4.77±0.62	3.69	4.05	84.82	1.38±0.37	1.97±0.71
CEC (meq/100 g)	3.30	52.50	13.67±1.41	12.61	9.15	66.92	2.07±0.37	6.94±0.71
BS (%)	2.13	98.10	36.43±3.89	31.00	24.90	68.35	0.95±0.37	0.65±0.71
OC (g kg^{-1})	2.30	27.70	7.36±0.70	6.25	4.54	61.62	2.70±0.37	9.47±0.71
TN (g kg^{-1})	0.40	3.66	0.86±0.09	0.70	0.59	67.86	3.29±0.37	12.47±0.71
C/N	2.77	17.68	8.99±0.46	8.67	3.02	33.59	0.77±0.37	0.96±0.71
Available P (mg kg^{-1})	0.00	40.00	7.02±1.33	3.75	7.95	113.27	2.43±0.37	7.48±0.71

SE: Standard error, CV: Coefficient of variation, Std. Dev.: Standard deviation

from 3.7-45.89 and 2.3-27.7 g kg^{-1} for surface and subsurface soils, respectively. The mean value of soil OC was higher in surface soils (13.58±1.20 g kg^{-1}) compared to subsurface soils (7.36±0.7 g kg^{-1}). Soil properties that were slightly variable (<15%) included pH-H_2O and pH-KCl, while the C/N ratio was moderately variable (25.26%) in surface soils. All the other soil properties were highly variable (>35%). As concerns subsurface properties, pH-H_2O appeared to be the only property with low variability (<15%). Properties with moderate variability included pH-KCl. All the other properties were highly variable especially the exchangeable bases (Table 2). Values of skewness and kurtosis indicate that sand, clay, pH-H_2O, BS and CN ratio were normally distributed. As concerns subsurface soils, properties that were normally distributed included sand, clay and C/N ratio. In surface soils, only pH-H_2O and C/N ratio showed a symmetric distribution, with skewness values being positive and <1. In subsurface soils only the C/N ratio showed a symmetric distribution with skewness value of 0.77.

Correlation analysis showed that there was a strong and positive relationship between OC and TN (r = 0.912, p <0.01 and r = 0.911, p <0.01 for surface and subsurface soils, respectively), indicating that soil total N increases with increase in OC (Table 3). In surface soils TN correlated positively and significantly with Ca^{2+}, Mg^{2+} and K^+. In subsurface soils TN correlated positively and significantly with Ca^{2+} and K^+. As concerns exchangeable cations (Na^+, K^+, Mg^{2+}, Ca^{2+}), BS and CEC, variability was high (>60%). Exchangeable Na^+, K^+, Mg^{2+}, Ca^{2+} and BS in subsurface soils had CV values higher than those of the surface soils. The mean values of exchangeable cations, CEC and BS were generally higher in surface soils, compared to subsurface soils, this as a result of higher OM content in surface soils.

Table 3: Correlation matrix of soil properties

Properties	Sand	Silt	Clay	pH-H_2O	pH-KCl	Ca^{2+}	Mg^{2+}	Na^+	K^+	Σ bases	CEC	BS	OC	TN	C/N	Avail. P
Surface soils																
Sand (%)	1															
Silt (%)	-0.823**	1														
Clay (%)	-0.909**	0.523**	1													
pH-H_2O	-0.057	0.056	0.040	1												
pH-KCl	-0.110	0.030	0.139	0.805**	1											
Ca^{2+} (meq/100 g)	-0.461**	0.502**	0.299	0.397**	0.365*	1										
Mg^{2+} (meq/100 g)	-0.581**	0.579**	0.466**	-0.073	-0.189	0.504**	1									
Na^+ (meq/100 g)	-0.304	0.424**	0.138	0.023	-0.118	0.366*	0.478**	1								
K^+ (meq/100 g)	-0.261	0.317*	0.157	0.120	-0.051	0.334*	0.080	0.485**	1							
Σ bases (meq/100 g)	-0.592**	0.609**	0.432**	0.246	0.142	0.881**	0.768**	0.451**	0.366*	1						
CEC (meq/100 g)	-0.577**	0.685**	0.388*	-0.227	-0.171	0.359*	0.583**	0.113	0.207	0.551**	1					
BS (%)	-0.248	0.270	0.152	0.503**	0.280	0.658**	0.329*	0.481**	0.314*	0.638**	-0.077	1				
OC (g kg^{-1})	-0.496**	0.592**	0.347*	-0.191	-0.110	0.355*	0.377*	0.093	0.283	0.475**	0.858**	-0.083	1			
TN (g kg^{-1})	-0.406**	0.611**	0.194	-0.201	-0.084	0.408**	0.347*	0.205	0.308*	0.438**	0.848**	-0.067	0.912**	1		
C/N	-0.195	-0.030	0.341*	-0.049	-0.145	-0.222	0.053	-0.251	-0.069	-0.112	0.003	-0.287	0.195	-0.137	1	
Avail. P (mg kg^{-1})	-0.099	0.233	-0.045	0.196	0.025	0.253	-0.060	0.438**	0.441**	0.177	-0.167	0.525**	-0.172	-0.052	-0.360*	1
Subsurface soils																
Sand (%)	1															
Silt (%)	-0.711**	1														
Clay (%)	-0.876**	0.452**	1													
pH-H_2O	0.112	0.205	0.058	1												
pH-KCl	-0.003	0.230	0.147	0.883**	1											
Ca^{2+} (meq/100 g)	-0.389*	0.475**	0.295	0.340*	0.306*	1										
Mg^{2+} (meq/100 g)	-0.323*	0.388*	0.271	0.190	0.015	0.558**	1									
Na^+ (meq/100 g)	-0.309*	0.349*	0.270	0.108	-0.097	0.414**	0.436**	1								
K^+ (meq/100 g)	-0.300	0.568**	0.122	0.187	0.117	0.530**	0.168	0.317*	1							
Σ bases (meq/100 g)	-0.399**	0.502**	0.307*	0.314*	0.192	0.891**	0.860**	0.469**	0.447**	1						
CEC (meq/100 g)	-0.486**	0.695**	0.305*	0.081	0.098	0.495**	0.531**	0.141	0.489**	0.589**	1					
BS (%)	-0.017	0.145	0.029	0.461**	0.284	0.619**	0.444**	0.486**	0.268	0.622**	-0.055	1				
OC (g kg^{-1})	-0.392*	0.602**	0.184	-0.037	0.037	0.391*	0.153	0.032	0.484**	0.338*	0.725**	-0.104	1			
TN (g kg^{-1})	-0.368*	0.644**	0.107	-0.038	0.079	0.465**	0.185	0.088	0.532**	0.381*	0.769**	-0.061	0.911**	1		
C/N	0.003	-0.038	0.166	0.202	0.052	-0.186	-0.083	-0.077	-0.100	-0.148	-0.145	-0.130	0.155	-0.209	1	
Avail. P (mg kg^{-1})	-0.040	0.217	-0.014	0.208	0.217	0.216	-0.007	0.221	0.215	0.129	-0.169	0.519**	-0.166	0.057	-0.346*	1

**Correlation is significant at $p<0.01$ (2-tailed), *Correlation is significant at $p<0.05$ (2-tailed), Avail. P: Available P

Establishment of soil management factors: Principal component analysis (PCA) yielded four components in surface soils and 5 principal components in subsurface soils (Table 4). Overall, the 4 PCs in surface soils explained a total of 81.08% of the variance in surface soil properties while the five PCs in subsurface soils explained a total of 83.63% of the variance in subsurface soil properties (Table 5). For surface soils, PC1 had high and positive loadings on exchangeable Mg^{2+} (0.87), Σ bases (0.81), CEC (0.89) and TN (0.80). For this reason, the component was termed the base status/nitrogen factor. The PC2 had high and positive loadings on pH-H_2O (0.89) and pH-KCl (0.86) and was named the soil acidity factor. The PC3 was named the P-K or mixed factor because of its high and positive loadings on available P (0.79) and exchangeable K^+ (0.81). The PC4 had a high and positive loading on C/N ratio (0.88) and was termed the soil organic matter factor because of the close link that exists between C/N ratio and SOM. For subsurface soil properties, PC1 was termed as the base status factor. The PC2 was named the soil acidity factor. The PC3 was named the soil K factor and PCs 4 and 5 were jointly termed the soil organic matter factor due to the high and positive loadings of PC4 on OC (0.906) and TN (0.89) and the high and negative loadings of PC5 on C/N (-0.87). Component plots in rotated space for surface (0-30 cm) and subsurface (30-60 cm) soil properties are shown in Fig. 1a and b, respectively.

In both surface and subsurface soils, all the properties were grouped into four common soil management factors namely base status, soil K, soil acidity and soil organic matter. Results of cluster analysis (dendrograms) are shown in Fig. 2a, b for surface and subsurface soils, respectively) and provide complementary information to the factors derived through PCA.

Table 4: Rotated component matrix[a] of soil properties

Soil properties	Components (factors) 1	2	3	4	5	Communalities
Surface soils (0-30 cm)						
Sand (%)	-0.832	-0.060	-0.233	-0.372		0.888
Silt (%)	0.780	0.087	0.332	0.088		0.735
Clay (%)	0.722	0.000	0.090	0.527		0.807
pH-H_2O	-0.245	0.897	0.145	0.146		0.908
pH-KCl	-0.172	0.866	-0.233	-0.119		0.848
Ca^{2+} (meq/100 g)	0.582	0.645	0.276	-0.208		0.875
Mg^{2+} (meq/100 g)	0.875	0.027	0.091	-0.047		0.776
Na^{+} (meq/100 g)	0.397	0.032	0.716	-0.264		0.740
K^{+} (meq/100 g)	0.086	-0.068	0.814	0.168		0.703
Σ bases (meq/100 g)	0.811	0.419	0.295	-0.097		0.930
CEC (meq/100 g)	0.897	-0.191	-0.114	0.039		0.855
BS (%)	0.247	0.653	0.559	-0.198		0.839
OC (%)	0.785	-0.224	-0.082	0.207		0.717
TN (g kg^{-1})	0.804	-0.266	0.016	-0.289		0.801
CN	0.091	-0.096	-0.207	0.884		0.842
Available P (mg kg^{-1})	-0.112	0.146	0.794	-0.214		0.711
Subsurface soils (30-60 cm)						
Sand (%)	-0.697	0.326	-0.410	-0.284	0.226	0.892
Silt (%)	0.639	-0.010	0.522	0.227	-0.132	0.750
Clay (%)	0.671	-0.096	0.334	0.268	-0.405	0.807
pH-H_2O	0.060	0.926	0.089	-0.238	-0.121	0.941
pH-KCl	-0.013	0.923	-0.084	-0.060	-0.104	0.873
Ca^{2+} (meq/100 g)	0.562	0.466	0.345	0.229	0.317	0.805
Mg^{2+} (meq/100 g)	0.880	0.240	0.010	0.005	0.175	0.863
Na^{+} (meq/100 g)	0.417	0.124	0.646	0.014	0.229	0.660
K^{+} (meq/100 g)	0.063	0.006	0.872	0.033	0.002	0.766
Σ bases (meq/100 g)	0.797	0.406	0.228	0.130	0.273	0.943
CEC (meq/100 g)	0.874	-0.128	-0.060	0.237	-0.044	0.842
BS (%)	0.213	0.629	0.434	-0.043	0.455	0.839
OC (%)	0.210	-0.065	0.053	0.906	-0.279	0.950
TN (g kg^{-1})	0.263	-0.193	0.050	0.891	0.212	0.948
CN	-0.119	0.329	0.041	0.056	-0.871	0.885
Available P (mg kg^{-1})	-0.160	0.252	0.440	0.004	0.580	0.620

Extraction method: Principal component analysis, Rotation method: Varimax with kaiser normalization, [a]Rotation converged in 12 iterations

Table 5: Variance explained by principal components

Components	Initial eigenvalues Total	Variance (%)	Cumulative (%)	Extraction sums of squared loadings Total	Variance (%)	Cumulative (%)	Rotation sums of squared loadings Total	Variance (%)	Cumulative (%)
Total variance explained for surface soils (0-30 cm)									
1	6.428	40.172	40.172	6.428	40.172	40.172	5.987	37.422	37.422
2	3.454	21.588	61.761	3.454	21.588	61.761	2.780	17.372	54.794
3	1.812	11.323	73.084	1.812	11.323	73.084	2.600	16.251	71.045
4	1.280	8.000	81.084	1.280	8.000	81.084	1.606	10.038	81.084
Total variance explained for subsurface soils (30-60 cm)									
1	5.763	36.018	36.018	5.763	36.018	36.018	4.213	26.332	26.332
2	3.341	20.881	56.899	3.341	20.881	56.899	2.906	18.160	44.492
3	1.891	11.817	68.715	1.891	11.817	68.715	2.310	14.437	58.928
4	1.295	8.093	76.809	1.295	8.093	76.809	2.010	12.565	71.493
5	1.092	6.828	83.637	1.092	6.828	83.637	1.943	12.143	83.637

Extraction method: Principal component analysis

Soil fertility levels in relation to oil palm growth: The proportions of soils with different soil fertility levels are shown in Table 6 for both surface and subsurface soil properties. Most of the soils (78.6%) have high pH levels while 19 and 16.7% of the soils have very high pH in surface and subsurface respectively. Thus, soil acidity is not a major constraint to oil palm productivity in the area. As concerns soil OC, more than 50% of surface soils have low to very low OC while >80% of subsurface soils have very low to low OC contents. In surface soils, more than 60% have total N content ranging from moderate to high while about 90% of subsurface soils have very low to low N content.

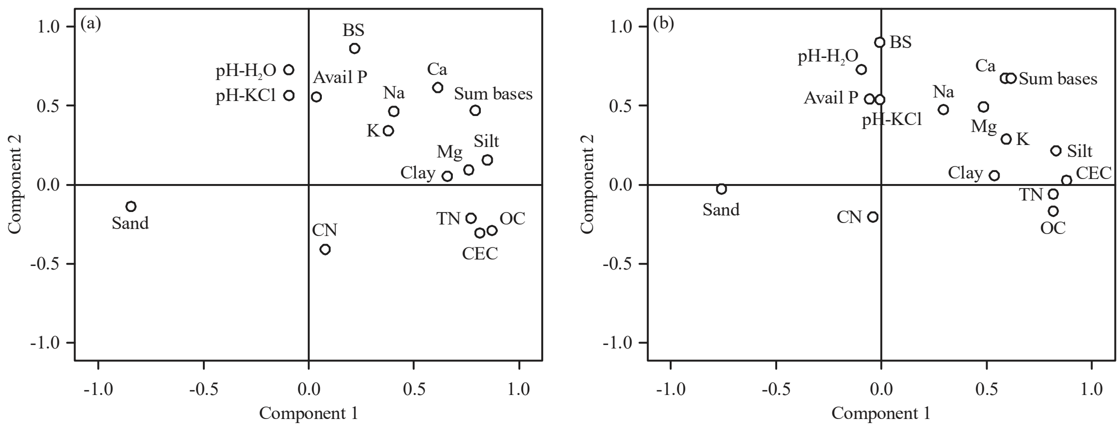

Fig. 1(a-b): Component plots in rotated space for surface (0-30 cm) and subsurface (30-60 cm) soil properties, (a) Surface soils and (b) Subsurface soils

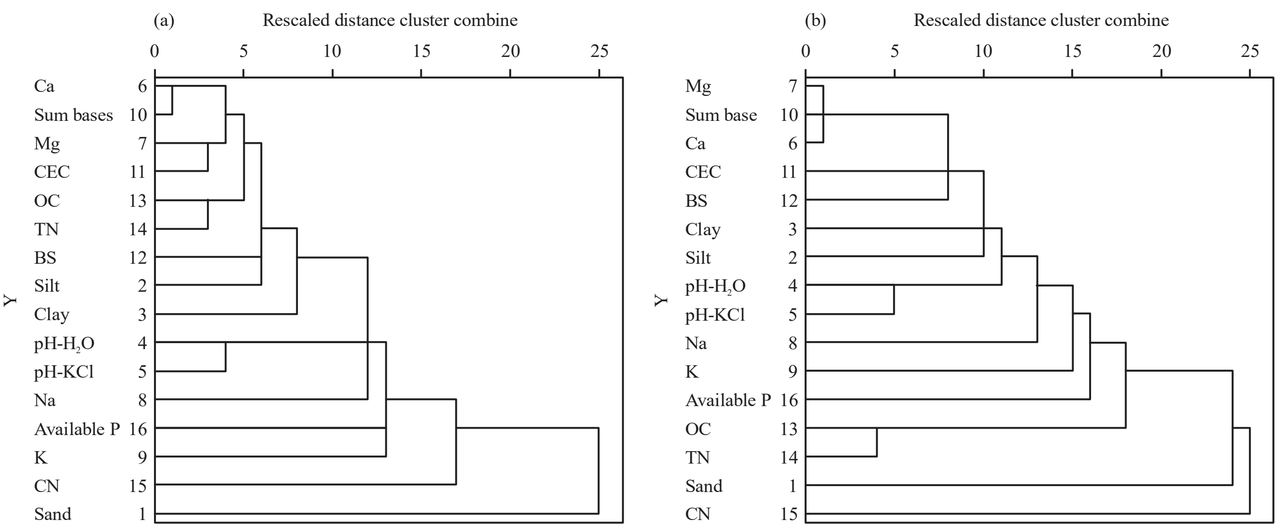

Fig. 2(a-b): Dendrogram of soil properties, (a) Surface (0-30 cm) soil properties and (b) Subsurface (30-60 cm) soil properties

Table 6: Percentages of soils with different soil fertility levels

Soil properties	Very low (%)	Low (%)	Moderate (%)	High (%)	Very high (%)
Surface soils (0-30 cm)					
Organic C (%)	0.0	2.4	0.0	78.6	19.0
Total N (%)	21.4	31.0	11.9	28.6	7.1
Available P (meq/100 g)	9.5	19.0	31.0	33.3	7.1
Exchangeable K (meq/100 g)	73.8	23.8	2.4	0.0	0.0
Exchangeable Mg (meq/100 g)	2.4	28.6	26.2	19.0	23.8
Subsurface soils (30-60 cm)					
Organic C (%)	0.0	2.4	2.4	78.6	16.7
Total N (%)	69.0	21.4	2.4	4.8	2.4
Available P (meq/100 g)	64.3	26.2	0.0	7.1	2.4
Exchangeable K (meq/100 g)	81.0	16.7	2.4	0.0	0.0
Exchangeable Mg (meq/100 g)	4.8	28.6	40.5	9.5	16.7

DISCUSSION

Soil properties generally varied more in subsurface horizons, due to higher spatial dependence range in subsurface soils compared to surface soils[23]. Contrary to the findings in this study, other studies found that there was a significant and negative correlation between OC and TN and between OC and C/N ratio in coastal plain sands of southeast Nigeria, even though the soils had low C/N ratios <20 (mean = 12.9) [24]. The pattern in particle size distribution observed is explained by the nature of the parent materials[16,24] and the relative degree of weathering of these soils[25]. Parent material plays a key role in maintaining the spatial variability of many physicochemical properties[26]. With regards to soil texture, the trend in variability for both surface and subsurface soils was similar to that reported in East Cameroon[27] and for a wide range of soil types in a Brazilian forest[23]. The high variability in particle size distribution observed in the present study reflects the diversity and heterogeneity of the parent materials.

The acidic nature of the soils in the Coastal lowland plains is in part due to the acidic parent materials and the high rainfall intensity which promotes the leaching of basic cations. Soil pH provides a good indication of the chemical status of the soil and can be used in part to determine potential plant growth in agro ecosystems[28]. The correlation between soil pH-H_2O with Ca^{2+} and BS indicates that soil pH increases with increase in Ca^{2+} concentration in the soil solution given that an increase in Ca^{2+} has a direct effect on reducing soil acidy[29]. In both surface and subsurface soils, there was a positive and significant correlation between BS and available P. This implies that as the pH increases, base saturation also increases and hence the concentration of available P also increases. At pH values <5.5, the precipitation of Al^{3+} may be a concern for Al toxicity, a condition which has been reported to cause restricted growth of roots and stems, leading to decreased use of subsoil nutrients[30-33]. The high variability in N, P and K indicate the need for developing and establishing site-specific nutrient management programs in different oil palm plantations as a solution for sustainable oil palm plantation management[34]. The retention and availability of these nutrients is intimately related to the type of predominant minerals present in the soil[13,35]. Soil texture can also affect P availability by influencing soil organic matter accumulation[36], soil microbial activity[37] and physicochemical equilibria involving different P species[38]. Soil organic matter has been reported to be the most influential property on soil productivity and levels of soil organic matter depend on plant factors such as litter production and decomposition rates and also on environmental factors such as temperature and water availability[39]. Soil organic matter and texture influence P dynamics and availability through various mechanisms[40,41,42].

With regards to the SOM factor, its proper management within agro ecosystems is a precondition for maintaining soil fertility and sustaining crop yields. SOM increases the water holding capacity of the soil, particularly in sandy soils. Also, SOM can reduce the P-sorption capacity of acidic soils[43], as is the case in this study. Available P is a key indicator of soil quality in agro ecosystems[44]. For high P-fixing soils such as oxide-rich soils derived from volcanic and ferromagnesian parent materials, management systems that are capable of accumulating and maintaining greater amounts of calcium-saturated soil organic matter in the surface soil would increase P availability from both organic and fertilizer sources, especially Ca-enriched fertilizers. In areas of high agricultural intensification, where a lot of chemical inputs are used, the buffering nature of the organic matter is considered to be advantageous in the residue management of pesticides, herbicides and heavy metals[45]. It has been reported that when the concentration of organic matter in the topsoil decreases, contamination of the environment by herbicides is likely to increase[46]. Within oil palm plantations, one of the main ways of increasing SOM involves the application of empty fruit bunches and pruned leaves, which go a long way to enhance soil chemical properties, thereby promoting vegetative growth and palm oil production[47,48].

As concerns the base status and the K factor, the proper management of exchangeable bases such as Ca^{2+}, Mg^{2+} and K^+ in soil is primordial for maintaining a balance of nutrients. It has been reported that higher rates of K in the soil solution allows for the efficient use of more nitrogen by crops[49,50], which results in better early vegetative growth and higher crop yields as K and N rates increase[49]. Additionally, crops respond to higher K levels when N is sufficient and greater yield response to N fertilizer occurs when K is sufficient[49]. Adequate potassium fertility is also important for the symbiotic relationship that enables bacteria to fix nitrogen from the air for use by legumes[49]. Although the correlations among the different cations were positive, PCA results showed that K^+ occurred in a separate component (PC3) from Mg^{2+} (PC1) in both surface and subsurface soils. With respect to soil nutrient management and uptake by plants, these results indicate that potassium management (e.g., K fertilization) should be done while taking into account the concentrations of Mg^{2+}. It has been reported that Mg^{2+} uptake is increased at lower concentrations of K^+ and that higher absorption of Ca^{2+} at low K^+ concentrations is believed to be due to high mobility of K^+, which when present in higher concentrations will tend to depress the absorption of other ions[50]. It has also been reported that Mg^{2+} or Ca^{2+} deficiency occurs from ion antagonism in acid soils following K^+ fertilization and in soils with high exchangeable[51] K^+. Thus, adequate quantities/proportions of these elements should be considered during fertilization. It is recommended that soil fertility investigations be regularly performed in order to achieve effective and profitable fertilization. Additionally, further studies should be conducted to establish a fertilizer recommendation system for oil palm in coastal plains of southwest Cameroon.

CONCLUSION

The results obtained from this study reveal that soil properties under oil palm plantations in coastal lowland plains of Southwest Cameroon are highly variable and necessitate site-specific soil fertility management for sustainable oil palm production. Based on the management factors derived, the main soil properties necessitating management attention with respect to oil palm production include base status (exchangeable K^+ and Mg^{2+}, CEC and base saturation), soil acidity (pH-H_2O), soil organic matter and available P content. A majority of the soils had low levels of organic matter, available P and total N. The proper management of these nutrients is one of the ultimate steps towards increased and sustainable oil palm production in this area. More specifically these measures include adequate organic matter incorporation into the soil and the application of correct amounts of N, P, K and Mg fertilizers.

SIGNIFICANCE STATEMENT

This study makes use of factor analysis to identify potential soil management factors necessary for sustaining oil palm production through site-specific nutrient management. This research is very important because it adds to information on soil properties supporting oil palms in coastal plains of southwest Cameroon. The findings from this research suggest that management factors that should be given particular attention include soil base status (exchangeable K^+ and Mg^{2+}, CEC and base saturation percent), soil acidity, soil organic matter and available phosphorus.

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