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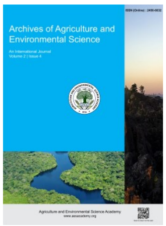

ORIGINAL RESEARCH ARTICLE

CrossMark

Determination of soil fertility constraints in two paddy soils of the western highland zone of Cameroon

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ABSTRACT

Information on soil fertility status and variability are essential in understanding the potential of soils and their management interventions in agriculture. The present study aimed at examining the soil quality or fertility of two paddy soils with different productivity in the Western High-land Zone of Cameroon. Twelve soil samples were collected in each of both study location at a standard depth of 0-30 cm and analyzed to find soil texture, Organic Carbon (OC), basic cations (Calcium Ca, Magnesium Mg, Potassium K and Sodium Na), Cation Exchange Capacity (CEC), soil pH, phosphorus (P), and Total Nitrogen (TN). Most measured soil characteristics showed different degrees of variability in soil nutrients ranging from low to very high in both soils. Both soils were acidic (pH <5.5), consistently deficient in total nitrogen, phosphorus, basic cations, and had high OC and CEC. Pearson correlation analysis and principal component analysis were used to identify appropriate soil quality indicators. P and Na in Koutaba and P, Mg, and CEC in Santchou constituted minimum data set (MDS) and accounted for 94% and 100% of the quality variation among soils. A Soil Quality Index (SQI) was developed base on the MSD method, Santchou and Koutaba received SQI of 0.48 and 0.73. The paddy soils of Koutaba were more fertile than those of Santchou. The low level of P and Mg were considered to be the major constraints limiting the productivity in both locations. These results suggest that, the manage-ment of inherent soil properties is based on-site specific situations.

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INTRODUCTION

Cameroon is a country with a typically agrarian economy. Agriculture employs more than 70% Cameroonians (Molua, 2010; PARM, 2018). Apart from industrial plantations and a few large private farms, small family farmers dominated cameroonian agriculture (MINADER, 2012). Productivity on these farms is low because of their poor soil fertility (Scott, 1992). These subsistence farms join the main targets of sustain-able actions to lift the majority of the population out of poverty. Rice, mainly considered as a cash crop, corresponds to the significant demand of the market. Cameroon's current demand for rice exceeds production and large quantities of rice are then imported to solve this problem of high demand (Goufo, 2008). This is caused by the fact that Cameroon's self-sufficiency in rice is only 19% (Tabi *et al*., 2013). Despite the efforts made by the public authorities and donors, national rice production has remained low. This challenges scientists about technology transfers and research to meet the country's goals with regard to this strategic commodity. The impact of climate change, soil degradation, and rapid population growth in Africa (around 3%/ year) among others (Macauley and Ramadjita, 2015) are all factors inhibiting the development of rice cultivation. The soil fertility status of rice-based agrosystems needs to be assessed to make sure stability in production. Sanchez *et al.* (2015) suggested that yields can triple in Africa through a clean and adequate soil management. Knowledge of the fertility status of a soil is essential for boosting yields through optimal cultivation practices.

Soil is one of the most important environmental factors considered as the main source in providing essential plant nutrients, water reserves, and a medium for plant growth (Ghaemi *et al.*, 2014; Kumar *et al.*, 2019). Declining soil quality emerges as an environmental and economic problem growing worldwide as degraded soils become more frequent due to their intensive use and poor management, often the result of overpopulation (Li and Lindstrom 2001; Eswaran *et al.*, 2005). Pressing problems like erosion, compaction, acidification, losses of organic matter and nutrients, and desertification decrease agricultural production (Stocking, 2003). The decline in soil quality has a severe influence on the environment and agricultural sustainability, as well as population health, food security, and subsistence (Karlen *et al.*, 2004). Land use and management strongly influence soil quality through a change in its physicochemical properties (Feyem *et al.*, 2007). Knowledge of soil quality is fundamental for sustainable agriculture (Tématio *et al.*, 2011; Kome *et al.*, 2018). This then shows that improper use and management reduces soil fertility, and then, food safety. Soil Quality Index (SQI) is the most right tool for assessing the sustainability of cultivation practice. This is due to its ease of use, flexibility, and quantification (Singh and Khera, 2009; Doran *et al.*, 2015; Zaid *et al.*, 2017; Dengiz, 2020).

In general, SQI is a useful assessment tool that may help move soil conservation (Gebreyesus, 2014) and resource management beyond assessments of soil erosion and changes in productivity (Andrews *et al.*, 2002). SQI can thus give the necessary information for planners and decision-makers to make informed decisions against soil quality degradation bring up proper interventions (Liu, 2015). Despite such importance of SQI in combating soil quality degradation, only a few studies were reported about various land use and soil management systems. This indicates that research on SQI has been mostly neglected for probable reasons, which could be technical and financial limitations. The qualities of a soil are its complex properties (nutrients available, oxygen, water, resistance to structural degradation) produced by combining soil characteristics. These properties are measurable amounts of the physical environment directly related to land use.

Several methods were developed to choose soil characteristics that can directly affect soil fertility or quality. We can distinguish: linear and multiple regression analysis (Li and Lindstorm, 2001), scoring functions (Yang *et al.*, 2010), principal component analysis (PCA) (Shukla *et al.*, 2006; Qi *et al.*, 2009; Supriyadi *et al.*, 2018) and discriminant analyses (Lima *et al.*, 2008). These retained soil characteristics were called indicators of soil fertility or quality. The aim of this study was to check soil physicochemical characteristics with a goal to give a comprehensive soil fertility status and constraints of two paddy sites in the Western Highland Zone (WHZ). In this study, PCA was used as the selection method for fertility indicators. Supriyadi *et al.* (2018) used PCA to select the soil characteristics most sensitive to soil quality for rice production.

MATERIALS AND METHODS

Description of study sites

Two lowland soils of the WHZ of Cameroon were considered in this study: Koutaba (Baigom plain) and Santchou (Mbo plain). WHZ extends between Latitudes 5° and 7°N and Longitudes 9° 50'' and 11°E. WHZ covers a surface of about 31,200 km^2 of which 14,800 km^2 are cultivable (MINAGRI, 2000). It has a sub-humid climate with two distinct seasons: a long raining season (mid-April to mid-November) and a short dry season (mid-November to mid-April). Mean annual rainfall is between 1720 to 2200 mm, mean minimum annual temperature is 18°C, and mean maximum annual temperature is 27°C (Tabi *et al.*, 2013). Because of its geomorphology, it has many types of soils: ferrallitic soil and hydromorphic soils in the lowland (Tabi *et al.*, 2013).

Soil sampling and analysis

Twelve soil samples were collected at each study site. The soil samples were taken at a standard depth of 0-30 cm. The reason for choosing this depth is that rice plant roots develop to this soil depth. Soil samples were air-dried and analyzed following standard procedures described by Pauwels *et al.* (1992). The soil characteristics measured were soil texture, Organic Carbon (OC), Exchangeable Bases, Cation Exchange Capacity (CEC), and soil pH.

Soil pH was measured using a pH-meter (Pocket-sized, HANNA Instrument) supplied with a glass electrode suspended in a soil-water solution ratio of 1:2.5. Organic carbon was determined by the Walkley and Black method, based on the oxidation of organic carbon by potassium dichromate ($K_2Cr_2O_7$). The determination of total Nitrogen was done by the method of Kjeldahl after hot mineralization of samples with a mixture of sulfuric acid and salicylic acid at 80°C. The distillate obtained using boric acid was titrated with 0.1 N sulphuric acid solutions. Exchangeable bases were extracted with 1 N neutral ammonium acetate solution and the extracted ions were determined using an atomic absorption spectrophotometer. CEC was determined using a 1 N solution of ammonium acetate at pH 7 following these steps: Saturation of the complex by NH_4^+ ion and extraction of exchangeable bases; Leaching with alcohol in order to eliminate saturated solution; Transfer of NH_4^+ ion by saturation of complex with a solution of 1N KCl; Titration of NH_4^+ after quantitative desorption by K^+. Available phosphorus was determined by the method of Bray II, with extraction using an acid solution of ammonium fluoride at pH 1.2 and coloration with blue of molybdenum. Particle size analysis (texture) was done by the Robinson Khön pipette method in the following steps: Destruction of organic matter by demineralized water; Treatment with dilute hydrochloric acid in order to destroy the coating of iron oxide; Washing the suspension with distilled water in order to eliminate the reagents; Wet sieving by using a sieve of 50 μm and treating with Sodium hexametaphosphate dispersant.

Determination of major soil fertility constraints

Principal component analysis (PCA) was conducted with the measured soil variables to select the most proper indicators. Only principal components (PCs) with eigenvalues >1, and which explained at least 5% of the variations in the data, were considered. Within each principal component (PC) only highly weighted factors (i.e., with absolute values within 10% of the largest factor loading) were retained for the Minimum Data Set (MDS) (Andrews *et al*., 2002; Liu *et al*., 2015). When more than one variable was retained in a PC, each was considered important and was retained in the MDS if the two considered values were not correlated (r<0.60) (Shukla *et al*., 2006). Among well-correlated variables within a PC, the variable with the highest weighted was selected for the MDS and was considered to be a constraint when its value was critical.

Soil Quality Index Computations

After measuring SQ indicators using field and laboratory analysis techniques, the SQI value was determined. Although the type of data used for each SQI may differ, the process of SQ indexing follows the same three basic steps regardless of the method described by Andrews and Carroll (2001). These steps are:

Indicators selection: Potential SQ indicators were selected based on their sensitivity to management practices, ability to describe major soil processes, ease and cost of sampling and laboratory analysis, and significance of increasing productivity (agronomic) and protecting environmental soil functions. The method for selecting a minimum dataset (MDS) was principal component analysis (PCA). Principal Component Analysis (PCA) was employed as a data reduction tool to select the most appropriate indicators of site potential for the study area from the list of the soil properties obtained in the laboratory. Only the PCs with eigenvalues >1 were considered for identifying the MDS (Andrews and Carroll, 2001; Rezaei *et al*., 2005; Yang *et al*., 2010). Within each PC, indicators receiving weighted loading values within 10% of the highest weighted loading were selected for the MDS (Wander and Bollero, 1999). When more than one variable was retained within a PC, the sum of the correlations was examined to determine if any variable could be considered to be redundant (Andrews *et al*., 2001). It was assumed that highly weighted variables were highly correlated, if their linear correlation (r) was >0.60.

Interpretation/Scoring/Transformation: After selecting the MDS using PCA, each value was transformed using the linear scoring technique (Gebreyesus, 2014). SQ indicator values were transformed to a common range between 0.1 and 1.0 using equations (1) and (2) (Velasquez *et al*., 2007).

$$Y = 0.1 + \left(\frac{(X-b)}{(a-b)}\right) \times 0.9 \quad (1)$$

$$Z = 1 - \left(\frac{(X-b)}{(a-b)}\right) \times 0.9 \quad (2)$$

Where *Y* and *Z* are values of the variables after transformation (score). *X* is the value of the variable to transform and a and b are the maximum and minimum threshold values of the variable. Equation (1) is used for the "more is better" scoring function, (2) for the "less is better," and a combination of both equations for the "optimum is better" scoring function.

Next, a multivariate approach PCA was used to establish weighting factors for each indicator. The weighting factor for each indicator was established by combining principal component decomposition properties, indicator loading factors, and the percentage of the variability explained by each eigenvector (λi). The individual percentage variance for the PCs retained was divided by the cumulative percentage of variance explained by all the retained PCs to yield the weighting factors (f_i) for retained PCs. The latent vectors of each variable for each PC were multiplied by the corresponding weighting factor (fi) to yield the product (λi×fi). The products obtained were summed and this value approximates the variable vector for each indicator. The summation was based on the vector of variable (xi) expressed as a linear combination of principal components (Rezaei *et al*., 2005). Because this variable vector should be scaled from 0 - 1, it was divided by the sum of the variable vector (∑xi), to give a weighting factor ρi, which is an approximation to the contribution of each indicator variable to overall soil quality.

Integration into Soil Quality Index

The soil quality index, whose classification is presented in Table 1, was calculated by multiplying each indicator score (S) with its corresponding weighting factor (ρi) and summing the products into an integrative index (Rezaei *et al*., 2005; Nguemezi *et al*., 2020):

$$\mathrm{SQI} = \sum \rho i \times \mathrm{Si} \quad (3)$$

Where ρ_i is a weighting factor for each indicator that was derived from a PCA for the ascribed indicator and S_i is the score for each indicator variable.

Data analysis: Data were subjected to statistical analysis using SPSS 23.0 (IBM Corporation) (Zaid *et al*., 2017). The student t-test method at a probability level of (*P>0.05*) was used to separate the mean difference of the soil characteristics.

Table 1. Classification of soil quality.

Value of SQI	[0 - 0.40 [	[0.40 - 0.55 [	[0.55 - 0.70 [	[0.70 - 0.85 [	[0.85 - 1.00]
Classification	Worse	Wrong	Good	Better	Excellent

Source : FAO (1976)

RESULTS AND DISCUSSION

Soil physicochemical characteristics

All soil physical and chemical properties were not significantly different for both paddy soils (in Koutaba and Santchou) with the exception of silt, Na, and Ca (Table 2). The percentage of silt was higher in the paddy soil of Koutaba (43.75%) than the paddy soil of Santchou (31.38%). The mean contents of clay and sand were, 29.25 and 25.53% in Koutaba and 30.75% and 38.00% in Santchou. The texture was Clay Loam (CL) for both paddy soils. This is the ideal texture for rice cultivation and can affect positively the nutrients circulation and rice root growth (Sys *et al*., 1991). The agricultural practice deteriorates physical soil properties (sand and silt) and makes it vulnerable to erosion because the macroaggregates have been destroyed (Celik, 2005). Soil erosion can change soil properties by reducing the depth of soil, changing its texture , and losing organic matter (Lal, 1997, 1998, 2001; Liu *et al.*, 2010). The sand and silt content are soil characteristics, which affected erosion and can be measured and used as a soil quality indicator to evaluate soil degradation under different agrosystems (Ayoubi *et al*., 2011).

Soil pH: The average values of soil pH were, respectively 5.27 and 5.24 in Koutaba and Santchou. Soil pH for both soils studied was not significantly ($p > 0.05$) different (Table 2). Soil pH varied between 5.00 and 5.60; showing that these soils were acidic. They absorb nutrients difficultly for plants' growth because rice plants do not grow optimally under acidic conditions. The best condition in terms of soil pH, for nutrient uptake by rice plants, is that soil pH which varies between 6.3 and 7.2 (Kyela, 2011).

Organic Carbon (OC) and Total Nitrogen (TN): The level of OC for both paddy soils ranged between 4.50% and 9.00%. The respective values of OC in Koutaba and Santchou were 6.87% and 3.91%.These values are not statistically different. According to standard value requirements for rice cultivation, these values are higher than the reference. These paddy soils have no constraint in terms of OC. Several researchers (Shukla *et al.*, 2006; Yemefack *et al*., 2006; Lima *et al*., 2008; Yao *et al*., 2013; Nanganoa *et al.*, 2020; Nguemezi *et al.*, 2020) have shown that organic matter is the main soil attribute responsible for the low fertility of multiple soils. The level of TN in both soils fell within the range of 0.16 - 0.40%. The values of TN were, respectively 0.27% and 0.26% in Koutaba and Santchou. There is no significant ($p > 0.05$) difference between these values (Table 2). Based on these results, the level of nitrogen in the study area is the same. The paddy soils studied have the same problem in terms of nitrogen. The level of TN was low when compared with the standard value for plant growth (Sawadogo, 2006).

Available phosphorus (P): No significant differences were observed for available P between paddy soils of Koutaba and Santchou. Their mean contents were respectively, 15.46 and 12.40 mg/kg. The values were higher than the critical value of 10 mg P/kg. The paddy soils studied have the same problematic problem in terms of available phosphorus. There is a phosphorus deficiency in this soil because the N/P ratio is greater than 2 (Sawadogo, 2006). A supply of phosphorus in the form of chemical fertilizers is therefore very essential for agriculture in the region. In tropical acidic soils, phosphate combines with iron and aluminum to form poorly soluble compounds that are not available to plants (Troeh and Thompson, 2005; Kotchi *et al*., 2010). This fixation and their degree of insolubility are the main causes of the low levels of available phosphorus available in the studied soils. These forms can be solubilized by microorganisms but this depends on the carbon available.

Table 2. Summary statistic of measured soil physical and chemical properties of paddy soils.

Soil attributes	Koutaba		Santchou	
	Mean±SD	Range	Mean±SD	Range
Clay (%)	29.25±7.33a	22.67 - 37.00	30.75±4.19a	28.00 - 37.00
Silt (%)	43.75±3.40a	41.00 - 48.00	31.38±3.09 b	27.00 - 34.00
Sand (%)	27.58±9.94a	18.00 - 36.33	38.00±6.27a	30.00 - 45.00
pH	5.27 ±0.19a	5.07 - 5.47	5.24±0.23a	5.05 - 5.52
TN (%)	0.27 ±0.09a	0.18 - 0.37	0.26±0.07a	0.16 - 0.31
OC (%)	6.87±2.16a	4.89 - 8.81	3.91±0.39a	3.40 - 4.27
C/N	25.05±4.27a	19.56 - 28.93	17.63±4.96a	13.00 - 24.00
P (mg/kg)	15.46±2.45a	11.92 - 17.19	12.40±1.46a	11.44 - 14.52
Na (cmol (+) Kg^{-1})	0.22±0.03 b	0.18 - 0.25	0.28±0.03 a	0.24 - 0.29
K (cmol (+) Kg^{-1})	0.44±0.07a	0.34 - 0.49	0.42±0.11a	0.27 - 0.52
Ca (cmol (+) Kg^{-1})	6.53±0.26 a	6.17 - 6.80	4.94±0.67 b	4.00 - 5.60
Mg (cmol (+) Kg^{-1})	3.12±0.76a	2.00 - 3.67	3.34±0.93a	2.20 - 4.20
CEC (cmol (+) Kg^{-1})	28.88±1.73a	26.88 - 30.74	28.43±1.40a	27.04 - 30.10

Means for the same property with different letters indicate significant differences at $p≤0,05$; SD = standard deviation.

Table 3. Results of Principal component analysis for Santchou soils.

Soil Quality Characteristics	PC1	PC2	PC3
Eigenvalue	5.87	4.86	2.27
% of Variance	45.12	37.42	17.47
Cumulative percent	45.12	82.53	100.00
		Factor loading	
pH	0.51	-0.86	-0.03
TN	-0.81	0.55	-0.19
OC	-0.53	-0.45	0.72
C/N	0.57	-0.81	0.13
P	-0.06	0.59	-0.81
Clay	0.93	-0.29	0.22
Silt	0.70	0.71	0.01
Sand	-0.98	-0.14	-0.12
Na	0.62	0.71	0.34
K	0.76	-0.12	-0.64
Ca	0.32	0.75	0.58
Mg	0.05	0.95	0.31
CEC	0.98	0.15	-0.14

Extraction Method: Principal Component Analysis.

Cation Exchange Capacity (CEC) and basic cations: CEC is a vital indicator of soil fertility and evaluated as an indicator of soil degradation and erosion. The respective values of the CEC were 28.88 cmol (+)/kg at Koutaba and 28.43 cmol (+)/kg at Santchou (Table 2). No significant difference was observed across the different soil productivity classes (Table 2). A comparison of these values with the guide guideline values shows that the CEC is high in these soils. A plausible explanation for this result is the clayey-silty texture of these soils and their high organic carbon contents. Koy (2009) showed that for a given soil, the CEC was determined by the relative amounts of the different colloids (clay, organic, etc.) present. The important nutrient reserves and high CEC were associated with the high levels of OM in these soils (Omoko, 1996; Yerima and Van Ranst, 2005). The average potassium K contents for the two soils were not statistically different. These soils have the same problem in terms of potassium. Their average contents were, respectively 0.44 and 0.32% (Table 2) in the soils of Koutaba and Santchou. The K/CEC ratio was less than 1. This means that there is a potassium deficiency in these soils (Sawadogo, 2006). The levels of sodium, Na in the two soils were, respectively 0.22 and 0.28% in Koutaba and Santchou. The calcium level in the two soils was 6.53 and 4.94%, respectively in Koutaba and Santchou. These soils are rich in exchangeable calcium (Table 2). A significant difference was observed between the values for the two soils, indicating that, the problem in terms of calcium in the two sites is different and is site specific. The average magnesium, contents were very high, respectively 3.12 and 3.34% in Koutaba and Santchou, and showed no significant difference between them.

Major soil fertility constraints

PCA was performed on all selected data for the soils sampled and revealed the presence of three and two components with eigenvalues >1 in Santchou and Koutaba, respectively.

In Santchou, under a varimax rotation, the first three principal components (PC) explained approximately 100% of the total variance (Table 3). The first principal component (PC1) has a high positive factor weight for soil characteristics such as CEC (0.98) and clay (0.93), and thehigh negative factor weight for sand (-0, 98). Since clay and sand are used to explain soil properties such as bulk density, soil texture, pore availability, and the ability to store and release nutrients, the component could be interpreted as the soil texture factor. CEC was significantly and positively correlated with clay (r ≤ 0.6) (Table 4) and negatively correlated with sand. CEC was considered very sensitive and was retained as an indicator of soil fertility under PC1. The factorial weight of the CEC was positive (0.98) shows that its increase through the supply of organic matter would increase the level of fertility. The second principal component (PC2) has a high factorial weight for Mg (0.95) and negative for pH (-0.86). The correlation matrix (Table 4) shows that Mg and pH were strongly correlated (| r | ≤ 0.6). Mg has the highest factor weight and was retained under PC2 as an indicator of fertility. Mg having a high and positive factor weight increases with fertility. The third principal component (PC3) has a high negative factor weight for P (-0.81). This shows that P does not favour soil fertility in the area. Increasing the dose of P would risk raising the pH through the formation of complexes between P and Ca, between P and Fe. Phosphorus was therefore considered to be an indicator of fertility. CEC, Mg and P were selected for the minimum data series (SMD) in the locality of Santchou. The fertility status in this area will be improved by adopting cultural practices aimed at increasing CEC, Mg and P.

Table 4. Correlation matrix of soil properties for Santchou soils.

	pH	TN	OC	C/N	P	Clay	Silt	Sand	Na	K	Ca	Mg	CEC
pH	1.00												
TN	-0.89	1.00											
OC	0.095	0.04	1.00										
C/N	0.99	-0.94	0.16	1.00									
P	-0.51	0.53	-0.81	-0.62	1.00								
Clay	0.72	-0.96	-0.20	0.80	-0.40	1.00							
Silt	-0.25	-0.18	-0.68	-0.18	0.37	0.45	1.00						
Sand	-0.38	0.74	0.50	-0.46	0.07	-0.90	-0.79	1.00					
Na	-0.31	-0.17	-0.40	-0.19	0.11	0.44	0.94	-0.74	1.00				
K	0.51	-0.56	-0.81	0.44	0.41	0.60	0.44	-0.65	0.16	1.00			
Ca	-0.49	0.04	-0.09	-0.35	-0.05	0.21	0.77	-0.49	0.93	-0.22	1.00		
Mg	-0.80	0.42	-0.23	-0.70	0.30	-0.16	0.72	-0.22	0.81	-0.27	0.91	1.00	
CEC	0.38	-0.69	-0.69	0.42	0.14	0.84	0.79	-0.97	0.66	0.82	0.34	0.15	1.00

Table 5. Result of Principal Component Analysis for Koutaba soils.

Soil quality characteristics	PC1	PC2
Eigenvalue	8.41	3.83
% of Variance	64.67	29.48
Cumulative Percent	64.67	94.15
	Factor loading	
pH	-0.27	0.95
TN	0.82	0.50
OC	0.97	0.24
C/N	0.60	-0.80
P	0.18	0.97
Clay	0.92	0.36
Silt	0.95	0.11
Sand	-0.94	-0.31
Na	-0.99	0.08
K	0.77	-0.46
Ca	-0.84	0.37
Mg	0.83	-0.52
CEC	0.87	0.42

Extraction Method: Principal Component Analysis.

Phosphorus (12.40 mg/kg) in this soil is low. Its contribution to soil fertility is negative. Fertility practices aimed at improving phosphorus content should be adopted. Among these practices, the use of fertilizers rich in P is one of them. CEC (28.43%) is high in this soil and positively contributes to the fertility status of this soil. This is due to the high content of clay and OC, which contribute to the absorption of exchangeable bases on the exchange complex. According to Nugroho and Istianto (2009), CEC is related to organic matter. The use of organic matter can improve the soil chemical properties such as CEC by increasing the availability of nutrients and preventing losses caused by leaching from rainwater (Souri, 2001; Kyela, 2011). Mg (3.34 cmol (+)/Kg) although high (3 - 8 cmol (+)/Kg), remains critical to maintain high soil fertility status. Cultural practices such as fertilization aimed at increasing it will be essential. Fageria (2013) indicated that there is a very close relationship between Mg and rice production in acidic soils.

In Koutaba, the first two principal components explained almost 94% of the total variance (Table 5). The first component has high negative and positive factorial weights for OC (0.97), clay (0.92), silt (0.95) and Na (-0.99), respectively (Table 5). All of these variables were found to be significantly correlated with each other (Table 6). Sodium (Na) had the highest factorial weight and then was retained as an indicator of soil fertility under PC1. Its contribution for the PC1 component was negative, meaning that its massive presence in the soil would degrade its fertility. The second component PC2 had high positive factor weights for pH (0.95) and P (0.97). Either will therefore increase or decrease with the fertility of the soil understudy. These two variables were strongly correlated (Table 6) i.e., the increase in pH would lead to the increase in phosphorus. Phosphorus has the highest factorial weight and was therefore retained under PC2 as an indicator of soil fertility. In other words, improving the fertility status in this area will go through practices that will help decrease the Na content and increase the amount of P. P and Na constituted the MDS for the locality of Koutaba.

Table 6. Correlation matrix of soil properties for Koutaba soils.

	pH	TN	OC	C/N	P	Clay	Silt	Sand	Na	K	Ca	Mg	CEC
pH	1.00												
TN	0. 30	1.00											
OC	-0.02	0.93	1.00										
C/N	-0.93	0.06	0.38	1.00									
P	**0.85**	0.59	0.40	-0.65	1.00								
Clay	0.12	0.98	0.99	0.24	0.49	1.00							
Silt	-0.20	0.75	0.92	0.51	0.32	0.86	1.00						
Sand	-0.06	-0.96	-0.99	-0.31	-0.46	-0.99	-0.90	1.00					
Na	0.36	-0.74	-0.93	-0.67	-0.11	-0.86	-0.96	0.90	1.00				
K	-0.58	0.52	0.66	0.78	-0.38	0.61	0.54	-0.63	-0.75	1.00			
Ca	0.64	-0.39	-0.69	-0.84	0.15	-0.57	-0.87	0.64	0.90	-0.64	1.00		
Mg	-0.68	0.48	0.69	0.88	-0.39	0.61	0.66	-0.64	-0.84	0.97	-0.80	1.00	
CEC	0.12	0.84	0.92	0.22	0.60	0.90	0.95	-0.92	-0.85	0.34	-0.68	0.44	1.00

Table 7. Soil Quality Index (SQI).

Site	Variables	Scoring function	Products λi×fi						
			λ1×f1	λ2×f2	λ3×f3	X_i=∑ λi×fi	ρ_i=X_i/∑ Xi	Si	SQI=∑$\rho_{i\times Si}$
Koutaba	P	More is better	0.12	0.68		0.80	0.71	0.70	0.50
	Na	Less is better	0.30	0.03		0.33	0.29	0.78	0.23
	∑					1.13			0.73
Santchou	P	More is better	-0.03	0.22	-0.14	0.05	0.05	0.38	0.02
	Mg	More is better	0.02	0.36	0.05	0.43	0.45	0.49	0.22
	CEC	More is better	0.44	0.06	-0.02	0.47	0.49	0.49	0.24
	∑					0.96	1.00		0.48

fi is the factorial loading of each PC; λi is the eigenvalue; xi score of the variable, ρ_i is the factorial loading and S_i is the score of the variable ; SQI : Soil Quality Index.

For Koutaba soil, P and Na were retained in the SMD. The factorial weight of P was positive while that of Na was negative. This shows that improving the soil fertility status of the Koutaba paddy field would require cultivation techniques that will help increase the phosphorus content and decrease or mitigate the effect of sodium. The increase in the phosphorus content in a soil is generally a function of the application of mineral fertilizers containing this element. When it comes to reducing sodium levels or mitigating their effect on crops such as rice, the application of mineral fertilizers containing potassium will be essential. Potassium, generally replaces sodium in its functions (osmosis) and some plants can thus successfully complete their life cycle without sodium (K + S Minerals and Agriculture, 2020). P is the only soil attribute that was retained as a common indicator of fertility for the two soils studied. The levels of this element in the two soils are not statistically different. This means that the phosphorus recommendation is the same throughout the rice study area. The recommendation for increasing the level of fertility in the study area is the effective use of right doses of chemical fertilizers on specific dates (Liu *et al*., 2010).

Soil Quality Index (SQI) is the most appropriate tool to assess the sustainability of a cultivation practice. This is due to its ease of use, flexibility and quantification (Drury *et al*., 2003; Singh and Khera, 2009). The SQI is a number between 0 and 1. When it is close to 1, the soil quality or soil fertility is excellent and the cultivation practices are sustainable.

Using the soil quality assessment criteria (Table 7), the Koutaba SQI (0.73) (Table 7) is between 0.70 and 0.85. These soils are therefore better in quality. This would be explained by cultural practices (use of organic fertilizers combined with chemical fertilizers, crop rotation with vegetable crops, etc.), which improve soil fertility. Cluzeau *et al.* (2005) have shown that crop rotation varies the demand for soil nutrients and avoids certain soil mineral deficiencies. In the rice-growing lowlands of Koutaba, rice cultivation is preceded or followed by intensive market gardening in some areas. Crop rotation and the combined use of chemical and organic fertilizers offer alternative management options for sustainable soil fertility (Bationo, 1997).

The positive effects of crop rotation are attributed to the ability of some vegetables to make soluble phosphorus strongly bound to calcium by exudating their roots (Bationo, 1995).

The Santchou Soil Quality is wrong because the SQI (0.48) is between 0.40 and 0.55 (Tables 1 and 7). This poor soil quality is explained by the low application of organic fertilizers, intensive and continuous plowing without rotation of crops including leguminous plants. Sanchez (2002) showed that when the leguminous trees of the genera *Sesbania*, *Tephrosia*, *Crotalaria*, *Glyricidia*, and *Cajanus* are interplanted into a young maize crop and allowed to grow as fallows during the dry seasons, they can accumulate 100 to 200 kg N ha1 over the period from 6 months to 2 years in sub-humid tropical regions of East and Southern Africa. It is obvious that the farmers of Santchou must adopt cultivation techniques can increase the level of soil fertility. To develop sustainable agriculture in this area requires a judicious use of local organic resources combined with good cultural practices (intercropping and crop rotations) and the use of chemical fertilizers at optimal doses (Aboudrare, 2009). Appropriate fertilization for sustainable production is possible by using organo-mineral fertilization (Bekunda *et al.*, 1999).

Conclusion

The physical characterization revealed that the soils of the studied sites have a predominantly clayey-loam texture in the surface horizons. The chemical characterization of these soils showed an acid reaction (pH <5.5). They are low in nitrogen, phosphorus, basic cations and have high organic carbon values and CEC. In the WHZ, the soil attributes do not have the same level, implying that their management cannot be the same. The recommendation for rice cultivation in the study area must be specific for a locality due to its fertility status. These soils need proper management techniques to raise their chemical fertility to the optimum level and increase agricultural production. P and Na in Koutaba and P, Mg and CEC in Santchou P and Na in Koutaba and P, Mg, and CEC in Santchou constituted minimum data set (MDS) and accounted for 94% and 100% of the quality variation among soils. Soils of Santchou and Koutaba received SQI of 0.48 and 0.73, respectively. The paddy soils of Koutaba were therefore more fertile than those of Santchou. The low level of P and Mg were considered to be the major constraints limiting the productivity in both locations. A recommendation to optimize soil fertility in the study area would be the efficient use of chemical fertilizers and crop rotation with leguminous plants.

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