Research Article

Relationships between soil fertility indicators and toposequence in the Sudano Sahelian watershed of Koutango in the southern peanut basin of Senegal

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Abstract

With the progressive land degradation, the use of watershed could be an alternative for cropping to achieve food security. By using statistical methods, this study aims to highlight relationships between different soil properties and toposequence in a 173.3 km²-watershed. Stratified soil sampling strategy associated with principal component analysis (PCA) and Chi-square ($\div^2$) test, have emphasized the variability of soil properties at the watershed scale. Soil physical and chemical properties analysis using standard methods, showed differences for soil organic carbon (OC) at the soil surface at the lowland level (5.51 g kg^{-1}), terraces (3.34 g kg^{-1}), colluviums (3.25 g kg^{-1}), and upland (3.13 g kg^{-1}). Cation exchange capacity (CEC) in the surface horizon also decreased along the toposequence with 3.36 Cmol kg^{-1} in the lowland and 1.93 Cmol kg^{-1} in the upland. The same trend was observed at the deep horizon for OC and CEC between the different soil units. PCA showed a correlation of 60%, 64% and 63% for surface, intermediate and deep horizons respectively between soil properties such as OC, CEC and ECEC. $\div^2$ test confirmed the influence of the toposequence on almost all soil properties measured, excepted with P in the surface horizons emphasizing the need to include agricultural practices that can influence soil variability.

Key words: Indicators of soil fertility, toposequence, watershed.

Résumé

Face à l'ampleur de la dégradation des sols, l'exploitation des bassins versants pour l'agriculture peut être une alternative pour assurer la sécurité alimentaire. Une stratégie d'échantillonnage stratifiée du sol, associée à l'analyse en composantes principales (ACP) et le test de Chi-deux ($\div^2$) sont implémentés pour valider la variabilité des propriétés du sol suivant la toposéquence d'un bassin versant de 173,3Km^2. L'analyse des propriétés physico-chimiques du sol montre une variation du carbone organique du sol (Co) dans les bas-fonds (5,51 g kg^{-1}), les terrasses (3,34 g kg^{-1}), les glacis (3,25 g kg^{-1}), et les plateaux (3,13 g kg^{-1}). La capacité d'échange cationique (CEC) a diminué le long de la toposéquence avec 3,36 Cmol+ kg^{-1} dans les bas-fonds et 1,93 Cmol+ kg^{-1} dans les plateaux. Cette même variabilité est observée dans les horizons de profondeur. L'ACP montre une corrélation de 60%, 64% et 63% respectivement pour les horizons de surface, intermédiaires et de profondeur notamment pour le Co, la CEC et les bases échangeables. Le test de $\div^2$ confirme l'influence de la toposéquence sur la variabilité des propriétés du sol mesurées, excepté le phosphore dans les horizons de surface, d'où la nécessité d'inclure les pratiques agricoles dans la recherche des indicateurs de fertilité des sols.

Mots clés : Indicateurs de fertilité des sols, toposequence, bassin versant.

Introduction

Managing soil resources for food security and sustainable environment deserves great attention considering the increasing pressure on soil, due largely to population increase and greater need for agricultural production. Farmers will begin to crop on new land as they are usually shifting cultivation through which the land is allowed to fallow for years in order for the organic matter and plant nutrients to build up before another cropping activity (*Udoh et al. 2013*). But this fallow period has now reduced drastically to one or two years (*Diack et al. 2000*). Such practice could create serious drawback such as decrease in soil fertility, increase in soil erosion and invasion by weeds (*Rumpel et al. 2006*). Farmers are beginning to farm on marginal lands such as steep slopes in many tropical countries. In the arid and semiarid regions such as the Sudano-Sahelian area, the process of degradation has intensified due to lack of farmer's knowledge of agricultural soil conditions, and lack of proper equipment. For example, studies conducted by *Feller (1995), Manlay (2000),* and *Loum et al. (2013)* were focused on indicators related to the cultural aptitudes of land for crop production. In these areas, the management of soil fertility poses sustainability issues due to the fragility of the agricultural potential of the land (*Ghaemi et al. 2014*). Fertility means the availability in the soil chemical components that can contribute to meeting the needs of the nutrients plants (*Pieri, 1989; Morel, 1989b*). However, in many parts of the world, the availability, use and profitability of inorganic fertilizers have been low whereas there has been intensification of land-use and expansion of crop cultivation to marginal soils (*Belachew and Abera, 2010*). Soil fertility decline is considered as an important cause for low productivity of many soils (*Lal, 1989; Sanchez, 2002*). When looking at soil physical properties, the soils are characterized, among other things, by a sandy texture, which greatly reduces their ability to retain water and results in a low CEC concentration. There is little clay and the clay present is Kaolinite, which is a highly weathered 1:1 layer clay mineral with a low CEC. The soils of the Sudano-Sahelian zone contain low levels of organic carbon (between 0.3 and 1.0 %). Despite their low concentrations, the soil physical and chemical properties, including soil organic matter, pH, the amount of clay and fine silt, and exchangeable cations (calcium, magnesium, potassium and sodium) are pivotal for the sustainability of agricultural production systems (*Yemefack et al. 2006*).

The objective of this study was to determine the level of correlation between the toposequence and the variability of the physical and chemical properties of the soil, using appropriate statistical methods, in order to contribute to the validation of indicators of soil fertility in Sudano-Sahelian farming systems.

The study zone

The watershed is drained by the Koular tributary which takes its source in the Gambia River (Figure 1). The climate is a Sudano-Sahelian type pattern characterized by two alternating seasons: a rainy season and a dry season. The rainy season lasts from June to October. A minimum temperature of 20°C occurs in January. Inter-annual rainfall volume varies between 400 and 1000 mm. The dry season lasts from November to May and is marked by high temperatures of around 35°C in April. The particularity of the watershed was the diversity of its topography composed of upland, colluviums, terraces and lowlands. In addition to this variability, farming activities were developed in the watershed by the population from the rural communities of *Paoskoto* and *Wack Ngouna* located in the administrative region of Kaolack (figure 1). The search for indicators of fertility related to the toposequence and their validation with statistical methods will allow to promote sustainable agricultural practices.

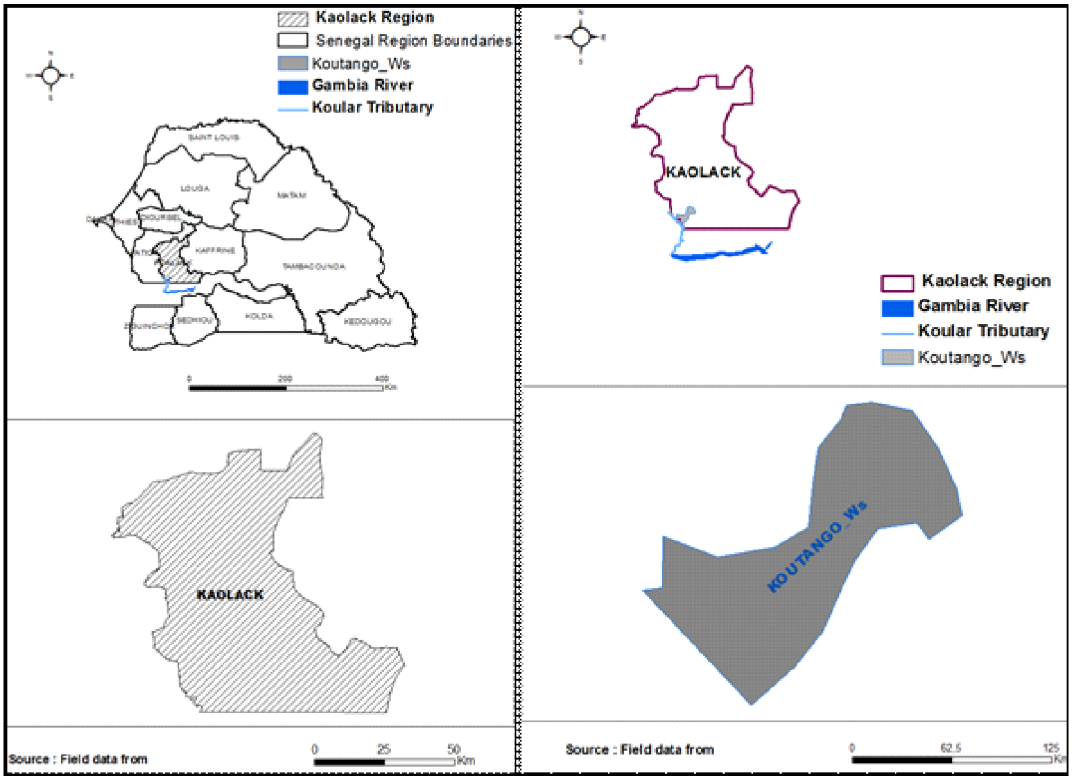

Figure 1 : Location of the Koutango watershed

Soil Sampling and Analysis

In this watershed, soil pits were dug using the transect method, base on a laminated plane along the toposequence. The watershed toposequence was divided into morphological units composed of lowlands, terraces, colluviums and upland. This layered approach had allowed to identify 12 transects distributed on both sides of the watershed. A soil pit was dug in each transect taking into account the variability of morphological units. 156 soil samples were hence collected from 46 soil profiles at xyz depths (in cm) described according to the *Duchaufour* method *(1977)*.

Laboratory Analysis

Soil pH was determined in duplicate both in distilled water and in 0.1N KCl solution, using a soil/liquid ratio of 1:2.5. After stirring for 30 minutes, the pH value was read off using a glass electrode pH meter (*Mclean, 1982*). Electrical Conductivity (EC) was measured by soil water ratio of 1:5. After shaking mechanically at 15 rpm for 1 hour, the EC was read using a glass electrode EC meter (*Rayment and Higginson, 1992*). The soil OC was obtained by the wet dichromate acid oxidation method (*Nelson and Sommers, 1982*); percentage organic matter was calculated by multiplying the value for organic carbon by the "Van Bermenalen factor" of 1.724, which is based on the assumption that soil organic matter contains 58 % Carbon *(Alison, 1982)*. Total nitrogen was determined using the Kjeldhal distillation method as described by *Bremmer and Mulvany (1982).* The ammonia from the digestion was distilled with 45% NaOH into 25% boric acid and determined by titrating 0.05N KCl. Available phosphorus was obtained using Bray11 bicarbonate extraction method as described by *Olsen and Sommers* (1982). Effective Cation Exchange Capacity (ECEC) composed of Ca, Mg, Na and K, were extracted in 1N NH_4OAC at pH 7. Sodium and K were determined with a flame photometer while Ca and Mg were determined with the atomic absorption spectrophotometer *(Rhoades, 1982a).* Cation exchange capacity was determined titrimetrically using 0.01 N NaOH. Particle size distribution was determined by the hydrometer method *(Gee and Bauder, 1986)*.

Statistical Analysis

The analytical data of soil properties were submitted to statistical processing using the R software (3.1.1, 2014), Excel, and Sigma Plot (version10). A pretreatment was first run a in Excel using a classification between the surface horizons (SH; 0-40cm), intermediate horizons (IH; 40-80cm) and deep horizons (DH; more than 80 cm). The Principal Component Analysis (PCA) and the Chi-square test were used to analyze the relationships between the toposequence and the physical and chemical properties of the soil.

Results

The results showed that soil chemical properties varied at the three depth levels within different soil units. Soil pH_{H20} varied from 5.71 to 5.85 with deep horizon having highest mean value (5.85) and the lowest at surface horizon. For the pH_{KCl}, the mean value ranged between 4.57 and 4.73 (Table 1). That of the phosphorus content was between 21.2 and 32.6 mg kg^{-1}. Within the watershed and throughout the different transects, physical and chemical properties showed a large range of values. EC also increased from 0.008 to 0.69 dS m^{-1}. The same trend was observed for organic carbon contents, going from 0.3 to 43.3 g kg^{-1}. The data ranged from 3.98 to 1.56 g kg^{-1}, an indication of decline downslope. Total N contents presented a quite high variability from 0.03 to 1.5 g kg^{-1}. Available P contents showed larger range with 2.55-170.0 mg kg^{-1}, also CEC concentration had a greater variability, 0.1-16.6 Cmol+ kg^{-1} (Table 2), along with the ECEC, ranging from 0.1 to 14.4 Cmol+ kg^{-1} and a dominance of Ca^{++}, followed by Mg^{++}, K^{+} and Na^{+}.

Tableau 1 : Mean variation of soil properties in relation to the toposequence

Soil properties	Surface Horizon	Intermediate Horizon	Deep Horizon
Sand (%)	89.56	84.15	3.61
Clay (%)	6.36	10.18	14.74
Silt (%)	4.07	5.67	81.65
pH H2O	5.71	5.74	5.85
pH KCl	4.69	4.57	4.73
C (g kg^{-1})	3.98	2.87	1.56
TN (g kg^{-1})	0.37	0.25	0.19
P Olsen (mg kg^{-1})	32.63	25.70	21.23
ECEC (Cmol+ kg^{-1})	1.88	1.89	2.84
CEC (Cmol+ kg^{-1})	2.71	3.06	2.85

Tableau 2 : Maximum and minimum variation of soil properties in relation to the toposequence

Soil properties	Surface Horizon		Intermediate Horizon		Deep Horizon	
	Maxi	Mini	Maxi	Mini	Maxi	Mini
Sand (%)	98.6	80.2	96.9	56.9	10.7	0.3
Silt (%)	11.7	0.5	28.3	0.3	98.4	54.4
Clay (%)	10.7	0.8	30	1.3	40.3	0.2
pH H2O	7.00	4.24	7.85	4.61	7.96	4.46
pH KCl	6.26	3.85	6.58	3.78	6.8	3.68
C (g kg^{-1})	6.26	0.64	24.6	0.39	5.95	0.2
TN (g kg^{-1})	2.25	0.05	1.43	0.07	0.56	0.03
P Olsen (mg kg^{-1})	170.00	3.02	150.41	2.52	161.34	0.50
ECEC (Cmol+ kg^{-1})	6.00	0.19	15.75	0.21	70.78	0.11
CEC (Cmol+ kg^{-1})	7.30	0.20	16.60	0.60	9.50	0.10

It has been noted an impact of the toposequence structure on the physical and chemical properties variability. The toposequence as well as the less important soil properties in the construction of the PCA axes are set as additional variables. This is the case for C/N ratio and sodium in the surface horizons, for sodium and potassium in the intermediate horizons and for sodium and calcium in deep horizons. The PCA has allowed justifying 60% of the properties variability for soil horizons (Figure 2), 64% of the variability for intermediate horizons (Figure 3) and 63% (Figure 4) for deep horizons. In addition, the PCA results are showing a positive correlation between the soil organic matter components (C and N), ECEC, CEC, silt and clay. The correlation between sand contents and pH is more pronounced in intermediate horizons and deep horizons than in surface horizons. There is also a negative correlation between sand contents and the levels of silt and clay.

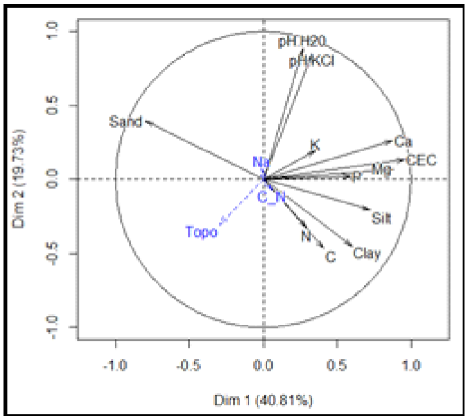

Figure 2 : PCA of soil properties (surface horizons)

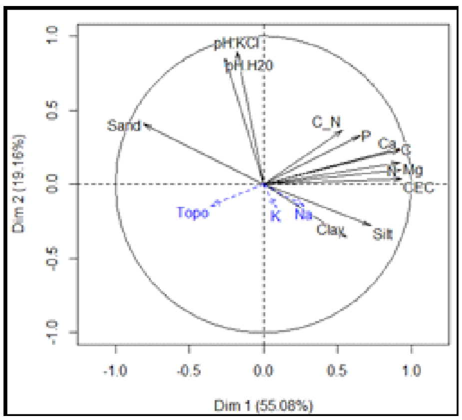

Figure 3 : PCA of soil properties (intermediate horizons)

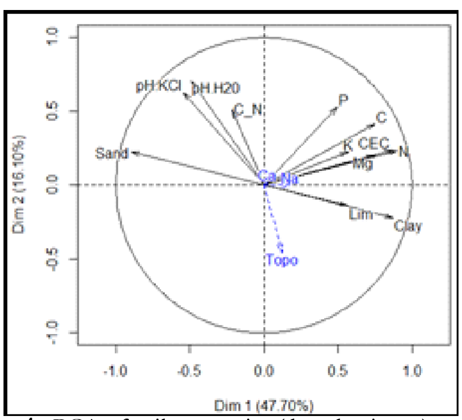

Figure 4 : PCA of soil properties (deep horizons)

With the Chi-square test, the relationships between the toposequence and soil properties were better highlighted, showing a significant effect for soil organic carbon with a probability of 53%. Regarding the distribution of phosphorus, the toposequence effect is null. For intermediate horizons, there is a greater significant toposequence effect for nitrogen, C/N ratio, potassium, sodium, pH, sand and clay with a probability of more than 70 % (Figure 5). The effect of the toposequence is marginally significant for organic carbon, CEC and calcium, with a probability between 10 and 30%. The toposequence has however no effect on the variability of silt and phosphorus. For deep horizons, the effect of the toposequence is significant on almost all soil properties except for phosphorus and calcium (Figure 6).

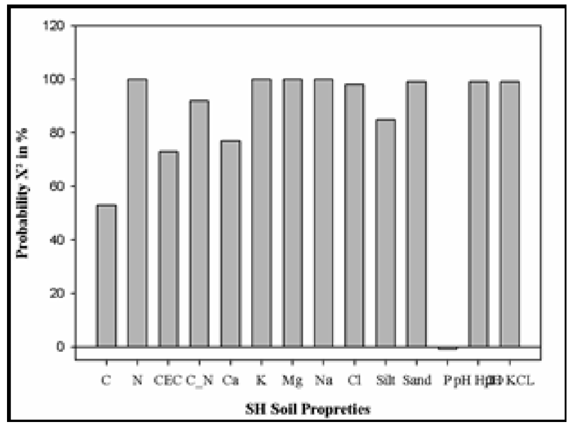

Figure 5 : X² Probability on surface horizons (SH)

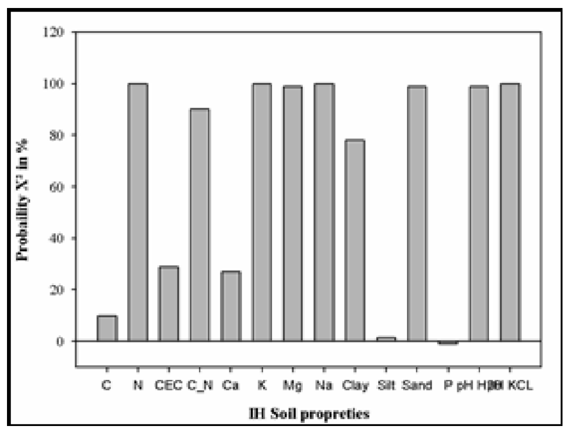

Figure 6 : X² Probability on intermediate horizons (IH)

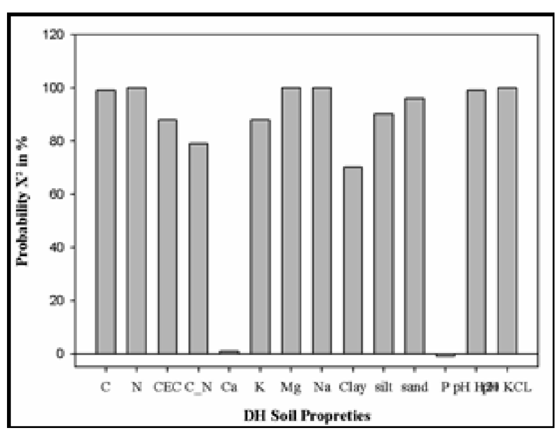

Figure 7 : X² Probability on deep horizons (DH)

Discussion

The high pH could be due to the wet and reduced soil conditions due probably to poor drainage leading to a dissolution process of most chemical elements susceptible to mineralization, while low soil pH at the soil surface may be associated with a well drained and oxidized soil condition. Also amount and type of fertilizers normally used and the amount of leaching could contribute to a low or a high soil pH value *Steenwerth et al. (2002).* High SOC at the uplands may be associated to its flatness, a characteristic that may offer some natural protection from erosion and hence SOC accumulation. Also, it may be that the movement of SOC is not related to erosion processes because soil carbon concentration is an equilibrium concentration that is more related to hill slope position and carbon inputs both from upslope and the immediate area *(Li et al. 2007)*. They further showed that SOC may be a direct product of mineralization rates rather than being more strongly related to the material deposited and eroded due to enhanced erosion process on disturbed hill slope. *Brubaker et al. (1993)* made similar observation that vegetative grasses in the uplands could have provided cover that protected loss of topsoil where most SOC is concentrated. The result indicates that clay content increases exponentially with SOC. Therefore, high clay content observed on lowlands does not necessarily reflect high SOC noted on uplands. *Ayanaba et al. (1996)* and *Ayuba (2001)* observed little variation in SOC due to clay content. Soil organic carbon plays an important role in water holding capacity, soil structure and overall soil health (*Mojiri et al. 2011*). However, the ability to sequester carbon in soil is influenced by the topography of an area in addition to the management practices, initial soil OC content, soil properties and land use changes (*Tschakert et al.* 2004; *Nuga, et al. 2006; Senthil et al. 2006*). The potential improvement in soil properties is dependent on soil texture. The larger potential for improving soil properties on fine textured soils can be attributed to the chemical connections formed between clay particles and organic matter. However, *Franzluebbers (2002)* found runoff to reduce under no-till for both sandy and clayey soils. Based on the analytical data of the soil properties, the level of variability of soil properties observed in the PCA exceeds 50% across all three horizons. This result demonstrates the relevance of the PCA in the exploration of soil data of the Sudano-Sahelian soils. The high correlation of soil properties in surface horizons indicated that the deep horizons may be explained by the vertical variability of organic carbon. The types of correlations between the physical and chemical soil properties noticed in the PCA also supported the correctness of the description procedure of soil profiles.

The impact of the toposequence on soil properties is confirmed when the probability is greater than or equal to 5%. Thus, for surface horizons, the test results are used to establish a relationship between the toposequence and almost all soil properties except available phosphorus. The lack of relationship with phosphorus can be explained by its generally very low quantities in Sahelian soils. Regarding intermediate horizons, there is, in addition to phosphorus, a lack of relationship between the toposequence and silt. This trend can be explained by the very sandy texture of the soils of the Koutango watershed and the much easier distinction between the coarse fractions (sand) and the finer fractions (clay).

For deep horizons, the relationship with the toposequence is not established for phosphorus and calcium. Lack of relationship with calcium can be explained by the decrease of soil chemical properties in deep layers, which needs to be justified primarily by the nature of the parent material of the Koutango watershed. *Mandal et al. (2008)* applied PCA for evaluating impact of irrigation water quality on a calcareous clay soil. Their results showed that PCA, as a multivariate statistical method, is a suitable tool for selecting effective soil indicators as minimum data set (MDS). Our results showed that using PCA to select the MDS from initial large of total data set (TDS) is in full agreement with the results of *Govaerts et al. (2006)* and *Shukla et al. (2004)*.

Conclusion

The application of statistical methods has allowed demonstrating, on one hand, the existing interrelationships between the soil physical and chemical properties and on the other, the impact of the toposequence on the variability of these physical and chemical properties. The PCA has established correlations between soil organic matter, CEC and ECEC. The Chi-square test also demonstrated the close relationship between the toposequence and almost all physical and chemical soil properties. Considering the three horizons (surface horizons, intermediate horizons and deep horizons), a total absence of relationship is only observed for phosphorus.

These results thus highlight the relevance of adopting a layered approach including terrain variability in the sampling protocol of soil properties of the Sudano-Sahelian farming systems. The correlations found between soil properties can also be used as a method for selecting the most accessible indicators of soil fertility to reduce costs in analyzing soil properties. However, a rigorous sampling strategy of soil properties must be developed before, which takes into account the structure of the toposequence. For future exploitation, these results raise the need to consider, in addition to the toposequence, other environmental variables of the soil, such as ground vegetation, slope and moisture indicators in the search for an impact from the variability of the physical and chemical properties of the soil. This approach may contribute to the development of an accurate model of the spatial and temporal changes in the physical and chemical soil properties of the Senegal peanut basin.

References

Allison, L. E. (1965). Organic carbon. In Methods" of Soil Analys'is, Part 2, ed. C. A. Black. Agronomy No. 9, Monograph Series, American Society of Agronomy, Madison, Wis., pp. 1367-78.

Ayanaba, S.B. Tuckwell and D.S. Jenkinson. 1996. The effects of clearing and cropping on the organic reserves and biomass of tropical forest soils. Soil Biochem 8, 519-525.

Ayuba H. K. 2001. Livestock grazing intensities and soil deterioration in the semi-arid rangeland of Nigeria: Effects on soil chemical (status. Discov. Innovate 13 (3-4), 150-155.

Belachew T. and Abera Y. 2010. Assessment of Soil Fertility Status with Depth in Wheat Growing Highlands of Southeast Ethiopia. World Journal of Agricultural Sciences 6 (5) : 525-531.

Bremmer JM, Mulvaney CS (1982). Total N, In: Page et al (eds) Methods of Soil Analysis. Part 2. 2nd ed. Agron. Monog. 9. ASA and SSSA, M adison WI. pp. 895-926.

Brubaker SC., Jones A. J., and D.T. Lewis Frank. 1993. Soil properties associated with landscape position. Soil Sci. Soc. Amer. J. 57, 235-239.

Diack M., Sene M., Badiane A. N., Diatta M. and R.P. Dick. 2000. Decomposition of a native shrub, *Piliostigma reticulatum*, litter in soils of semiarid Senegal. J. of Arid Soil Research and Rehabilitation 14 (3): 205-218.

Duchaufour P. 1977. Pédologie : sol, végétation, environnement. Abrégés de Pédologie. Masson 5ème édition, 291 p.

Feller C. 1995. La matière organique du sol : un indicateur de la fertilité. Application aux zones

sahélienne et soudanienne. Agriculture et développement, 8, 7 p.
Franzluebbers A. J. 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil & Tillage Research 66, 197–205.

Gee, G.W. and Bauder J.W. 1986. Particle Size Analysis. In: Methods of Soil Analysis, Part 1. A. Klute (ed.). 2nd Ed., Vol. 9. Am. Soc. Agron., Madison, WI, pp: 383-411.

Ghaemi, M., A.R. Astaraei, H. Emami, M. Nassiri Mahalati and S.H·Sanaeinejad. 2014. Determining soil indicators for soil sustainability assessment using principal component analysis of Astan Quds- east of Mashhad – Iran. Journal of Soil Science and Plant Nutrition, 14 (4) 987-1004.
Govaerts B., Sayre Ken D., J. Deckers. 2006. A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. Soil and Tillage Research, Vol. 87, Issue 2, 163–174.

Lal, R. 1989. Land Degradation and Its Impact on Food and Other Resources; Food and Natural Resources, pp: 85-140.

Li Y., Zhang Q.U., Reicosky D. C.., Lindstrom M. G., Bai L.Y., and L. Li. 2007. Changes in SOC induced by tillage and water erosion on a steep cultivated hillslope in the Chinese Loess plateau from 1898-1994 and 1954-1998. J. of Geophysical Res., 112

Loum M., Viaud V., Fouad Y., Nicolas H., C. Walter. 2013. Retrospective and prospective dynamics of soil carbon sequestration in Sahelian agrosystems in Senegal. Journal of Arids Environnment, 100-101, pp. 100-105.

McLean, E.O., 1982. Soil pH and lime requirement. In: Methods of soil analysis, Part 2. (Edited by A.L. Page, R.H. Miller and D.R. Keeney). American Society of Agron Chi-square, Madison, Wisc, pp: 199-224.

Mandal U. K., Warrington D.N., A.K. Bhardwaj A. K., A. Bar-Tal A., Kautsky L., Minz D., G.J. Levy. 2008. Evaluating impact of irrigation water quality on a calcareous clay soil
using principal component analysis. Geoderma 144, 189–197.

Manlay R., 2000. Dynamique de la matière organique à l'échelle d'un terroir agro-pastoral de savane ouest-africaine (Sud-Sénégal). Thése de Doctorat, Ecole Nationale du Génie Rural, des Eaux et Forêts Centre de Montpellier. 326 pages.

Mojiri A., Kazemi Z. and Amirossadat Z. 2011. Effects of land use changes and hillslope position on soil quality attributes (A case study: Fereydoonshahr, Iran). African Journal of Agricultural Research Vol. 6(5), pp. 1114-1119.

Morel R. 1989b. La fertilité des sols in : les sols cultivés. Lavoisier, Paris, 341-363. Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter: In: A.L. Page, R.H. Miller and D.R. Keeney) Methods of soil analysis. Part 2 Chemical and Mirobiological Properties, pp: 539-579.

Nelson, D. W. & Sommers, L. E. 1982. Total carbon, organic carbon, and organic matter. In Methods" of Soil Analysis, Part 2, ed. A. L. Page. Agronomy No. 9, Monograph Series, American Society of Agronomy, Madison, Wis., pp. 539-79.

Nuga B. O., Eluwa N. C., Akinbola G. E., C.C. Wokocha. 2006. Characterization and classification of soils along a Toposequence in IKwuamo Local Government Area of Abia State Nigeria, Agricultural Journal 1(4), 192-197.

Olsen SR, Sommers L. E. 1982. Phosphorus. In: Page AL, et al (eds), Methods of Soil Analysis, Part 2, 2nd edn, Agron Monogr 9. ASA and ASSA, Madison WI, pp 403–430.

Pieri C. 1989. Fertilité des terres de savanes: bilan de trente ans de recherche et de développement agricole au sud du Sahara. Ministère de la coopération française, CIRAD-IRAT, 444 pages.

Rayment, G. E. and Higginson, FR. 1992. Australian Laboratory Handbook of Soil and Water Chemical Methods,Melbourne, Inkata Press (Australian Soil and Land Survey Handbooks, Vol. 3).

Rhoades J. D. 1982a. Cation exchange capacity. In: Page, A.L. (Ed.), Methods of Soil Analysis Part 2. 2nd Edition Agron. Monogr. 9. ASA, Madison, WI, pp. 149-157.

Rumpel C., Alexis T. M., Chabbi A., Chaplot V., D.P. Rasse D. P., Valentin C., A. Mariotti. 2006. Black carbon contribution to soil organic matter composition in tropical sloping land under slash and burn agriculture. Geoderma 130, 35–46.

Sanchez, P.A. 2002. Soil fertility and hunger in Africa. Sci., 295(5562): 2019-2020.

Senthil K. S., Kravchenko A. N., G.P. Robertson. 2006. Soil carbon sequestration as a function of initial carbon content in different crop management systems of a long-term experiment. In: Abstracts 18th World Congress of Soil Science, Inter. Union of Soil Science (IUSS), USA. SOM stabilization and carbon sequestration papers, 139-144.

Shukla M.K., Lal R., M. Ebinger. 2004. Principal component analysis for predicting corn biomass and grain yields. Soil Sci. 169, 215–224.

Steenwerth K. L., Louise E. Jackson L. E., Francisco J. Calderon F. J., Stromberg M. R, Kate M. Scow K. M. 2002. Soil microbial community composition and land use history in cultivated and grassland ecosystems of coastal California. Soil Biology & Biochemistry 34, 1599–1611.

Tschakert P., Khouma M., M. Sène. 2004. Biophysical potential for soil carbon sequestration in agricultural systems of the Old Peanut Basin of Senegal. Journal of Arid Environments, 59:511-533.

Udoh B.T., Esu I. E. , Ibia T. O., Onweremadu E. U. and S. E. Unyienyin. 2013. Agricultural Potential of the Beach Ridge Soils of the Niger Delta, Nigeria. Malaysian Journal of Soil Science Vol. 17: 17-37.

Yemefack, M., Jetten, V.G., D.G. Rossiter. 2006. Developing a minimum data set for characterizing soil dynamics in shifting cultivation systems. Soil Till Res. 86, 84–98.

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