Soil Quality Assessment of the Lower Niger River Plain Alluvial Soils in Bayelsa State, Nigeria, for Sustained Productivity

Achimota Ayadei Dickson

Department of Soil Science, Faculty of Agriculture, Niger Delta University, Wilberforce Island, Nigeria

Email address:

achimotadicksom@ndu.edu.ng

Abstract: Floodplain soils worldwide are very useful for agricultural production and food security. But, the floodplains of Bayelsa State are under-utilized due to lack of technical information and knowledge on the nutrient status and other soil characteristics. This study therefore, assessed the soil quality of lower Niger River floodplain soils in Bayelsa State, Nigeria for sustained productivity and food security. Alluvial soils from different river plains in Bayelsa State, Southern Nigeria were characterized and fertility assessed. Pedogenic soil samples from the levee crest, middle slope, lower slope and recent alluvial soils from the channels of present active rivers were collected from identified genetic horizons of soil profiles and analyzed for physical and chemical properties using standard methods and the soils fertility status evaluated using Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF). The soils were dominantly silt loam followed by silty clay loam and loam except Elemebiri 3 (ELM3) and Trofani 3 (TFN3), dominated by loamy sand and sandy loam. pH (5.31-7.00) was moderately acid to neutral and organic matter content, generally low to moderate, ranging from 0.19-3.88%. Total N values was also low while available P was low to moderate. The exchange complex was dominated by Ca^{2+} and ECEC values were low. The SFI values were higher than the SEF values in al the Soil Mapping Units (SMUs), contributed by pH, organic matter and phosphorus. Both SFI and SEF values decreased with increase in depth for all the soil mapping units except Trofani 1 (TFN1) where the bottom layers recorded higher SFI values and Elemebiri 3 (ELM3) for SEF. Though the soils nutrient concentration was generally low to moderate, both SFI and SEF evaluated the soils as fertile contributed mainly by organic matter, available P and pH. Since biomass accumulation contributed greatly to improvement of soil fertility and physical structure, soil organic matter maintenance should be given top priority in these soils for sustained productivity and food security.

Keywords: Soil Quality Assessment, Soil Fertility Index, Soil Evaluation Factor, Lower Niger River, Soil Productivity

1. Introduction

Soils in agricultural production play a vital part of the ecological system which produces food and fiber for human use. Currently, sustainable and productive agriculture is highly related to soil quality [1]. And floodplain soils worldwide are very useful for agricultural production and food security due to the huge reserve of available nutrients for crop plants utilization. Several authors [2-4] proposed efficient management of floodplain soils to ameliorate the problem of poor agricultural productivity in Nigeria. According to [3], agricultural projects under River Basin development scheme in Nigeria vigorously pursued arable crop production,

utilizing mainly floodplain and valley bottom soils and to some extent the adjoining uplands. In spite of the serious attention given to floodplain agriculture under River Basin development scheme in Nigeria, technical information and knowledge on the nutrient status and other soil characteristics on the floodplain soils of Bayelsa State are inadequate, not current and incomplete [5]. Consequently, the floodplains of Bayelsa State are under-utilized. The need, therefore, to characterize and comprehensively evaluate their fertility using recently developed indices to equate them to, crop production, which definitely, could help local farmers in effective management and ensure food security cannot be over emphasized. Land degradation according to [6] is a serious

threat in Sub-Saharan Africa, where nearly 67 percent of the total land is degraded from light to a severe extent. Accordingly, [] emphasized that finding appropriate methods of evaluating soil conditions in the tropical rainforest is hindered due to the complexity of soil properties [7]. Moran et al. [8, 7], however, used soil fertility index (SFI) and soil evaluation factor (SEF), respectively, as a comprehensive factors to represent soil fertility and indicated that soils with SEF value < 5 indicated extremely poor soil fertility and those with > values signified fertility. In this study, Soil fertility evaluation (SFI) and Soil SEF were used as soil assessment tools to assess the quality of the soil mapping units.

2. Materials and Methods

2.1. Locations and Description of the Study Area

The study was carried out within Bayelsa State from the Niger Delta region, Southern Nigeria. The study locations lie between latitude 05°22'03.9"N and 04°59'08.9"N and longitude 006°30'21.1"E and 006°06'54.1"E. The Niger River traverses Nigeria in a Northwestern to Southern direction with the attendant sediment load ensuring that the delta platform ends up as flat terrain, making it a unique geologic environment. The Niger River flows southward and breaks up into Forcados and Nun Rivers: The Nun River, running north and south down the middle of the Bayelsa State, which remains the most direct tributary of the Niger while Forcados River demarcates the western borders of the state. From Bayelsa State's territory issues several rivers into the Atlantic Ocean, namely the Ramos, Dodo, Pennington, Digatoru, Middleton, Koluama, Fishtown, Sangana, the Nun, Brass, St. Nicholas, Santa Barbara and Sombreiro (Figure 1). The annual rainfall of the study area ranges from 2000 to 4000 mm, spread over 8 to 10 months of the year. Relative humidity is comparatively uniform (average over 80%) all over the state due to proximity to the Atlantic Ocean. Temperature is fairly constant with a maximum of 30°C. The natural vegetation is tropical rainforest but much of the original vegetation is presently degraded or altered. Food crop production is carried out on the levee crest, levee slope, backslope and on recent alluvial soils on channels of present active rivers. Levee crest soils are no longer flooded while most flood plain soils and alluvial soils in the channels of present active rivers are flooded yearly by the Niger River floods.
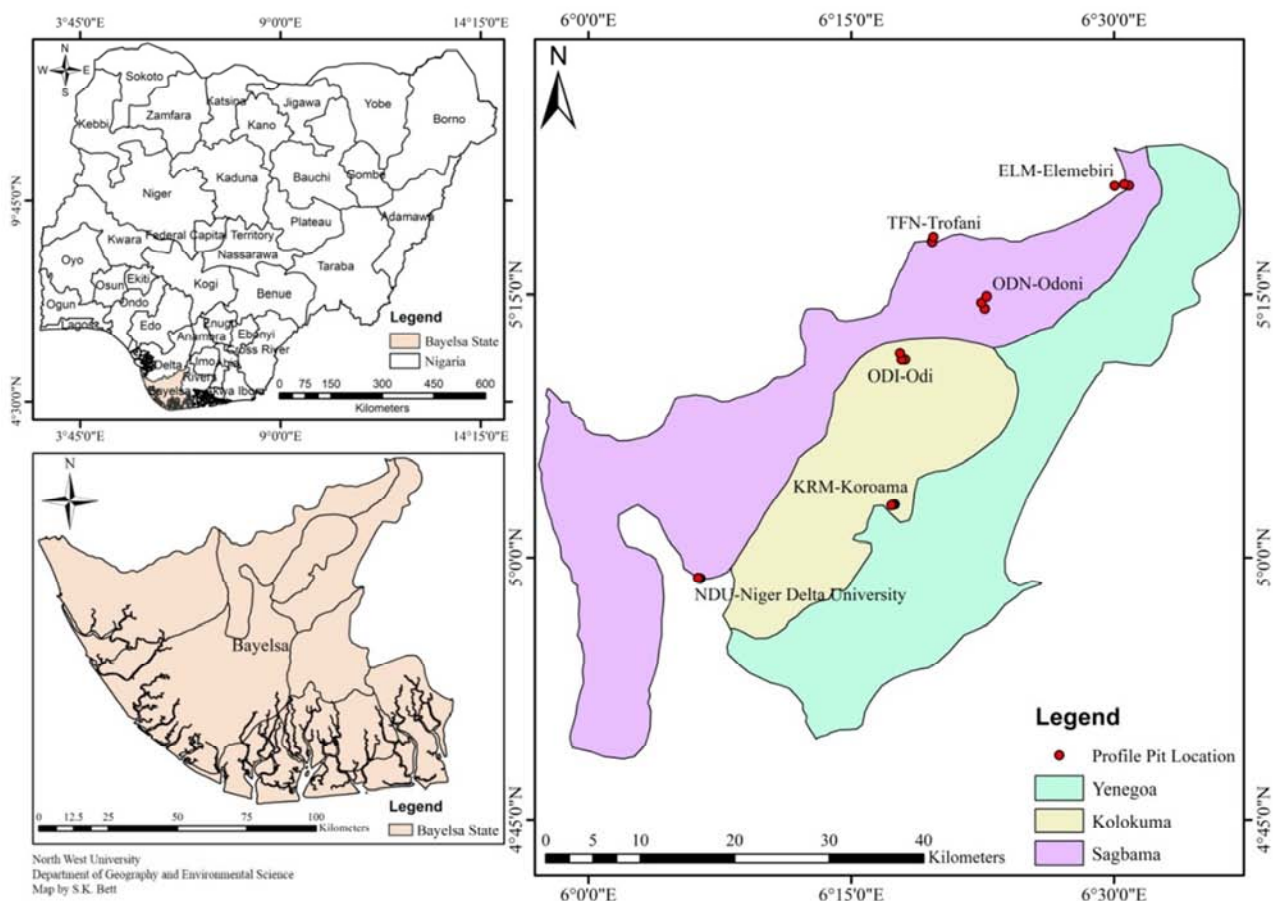

Figure 1. Map of Bayelsa State showing Sampling Points.

The designations of the soil mapping units were ELM1, ELM2 and ELM3 for Elemebiri, ODN1, ODN2 and ODN3 for Odoni, TFN1, TFN2 and TFN3 for Trofani. Details of the soil mapping units and the area covered are presented in Table 1.

Table 1. *Soil Sampling Units, Profile Pit Location and Land Area.*

Study Location	Sampling Unit	Geo-reference of Profile Pit	No. of Profile Pits	Land Area (Hectares)	Land Area (%)
	ELM1	N 05°21'11.5"E 006°30'02.2"	1	29.08	2.4
Elemebiri	ELM2	N 05°21'12.4"E 006°30'51.3"	1	21.25	1.7
	ELM3	N 05°21'22.6"E 006°30'51.3"	1	162.14	13.3
	ODN1	N 05°14'12.4"E 006°22'37.2"	1	89.94	7.4
Odoni	ODN2	N 05°14'33.3'E 006°22'25.5"	1	52.10	4.3
	ODN3	N 05°14'53.3"E 006°22'43.4"	1	90.57	7.4
	TFN1	N 05°18'01.5"E 006°19'36.0"	1	87.61	7.2
Trofani	TFN2	N 05°17'58.6"E 006°19'37.1"	1	51.50	4.2
	TFN3	N 05°18'17.1"E 006°19'41.2"	1	148.51	12.2

2.2. Soil Sampling and Analyses

Agricultural lands from six communities, namely Elemebiri by Lower River Niger, Odoni and Odi by Nun River, Trofani by Forcados River, Koroama by Taylor Creek and Niger Delta University by Igbedi Creek were surveyed. The communities were chosen due to their contributions to food production in the state and location. Soil samples were collected from identified genetic horizons of soil profiles. The horizon-wise soil samples were air-dried, crushed and sieved to pass through a 2 mm. Soil analyses were carried out in the Green River Project laboratory of the Nigerian Agip Oil Company and Zadell laboratory, Port Harcourt. Standard laboratory methods were used to determine the physical and chemical properties of the soils as reported in [9].

2.3. Statistical Analysis

Principal component analysis (PCA) was performed to detect the most prominent soil parameters that influence the fertility of the soils, as the data involved several samples. Pearson's correlation analysis was performed to determine the relationship between the selected soils properties while the fertility and site quality of the soil mapping units were estimated using Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF) [5] using the following formula:

$$\text{SFI} = \text{pH} + \text{organic matter (\% dry soil basis)} + \text{Avail. P (mgkg}^{-1}\text{dry soil} + \text{Exch. K (cmol}_c\text{kg}^{-1}) + \text{Exch. Ca (cmol}_c\text{kg}^{-1}) + \text{Mg (cmol}_c\text{kg}^{-1}) - \text{Exch. Al (cmol}_c\text{kg}^{-1}) \text{ (Sauce: [8])}$$

$$\text{SEF} = [\text{Exch. K (cmol}_c\text{kg}^{-1}) + \text{Exch. Ca (cmol}_c\text{kg}^{-1}) + \text{Exch. Mg (cmol}_c\text{kg}^{-1}) - \{\log(1 + \text{Exch. Al (cmol}_c\text{kg}^{-1})\}] \times \text{organic matter (\% dry soil basis)} + 5 \text{ (Sauce: [9])}$$

All statistical analyses were performed using SPSS version 21.

3. Results and Discussions

3.1. Physico-chemical Properties of the Soils

The texture of the soils was dominantly silt loam followed by silty clay loam and loam except ELM3 and TFN3, dominated by loamy sand and sandy loam (Figures 2). The dominance of sand in ELM3 and TFN3 (Figure 2) indicated that the SMUs have high infiltration rate and low water holding capacity with possibility of moisture stress during dry months [10, 11]. The clay distribution within ELM1, ELM2, ODN1, ODN2, ODN3, TFN1 and TFN2 SMUs was irregular. Lawal et al. reported irregular distribution of clay within the subsoil of three pedons, characteristic of cambic horizon [13]. Though the distribution of silt/clay ratio was also irregular with depth, silt/clay ratios generally increased with increase in silt content and vice versa. Higher silt/clay ratio in the surface layers reflected annual alluvial enrichment of the surface through deposition by the annual floods. Egbuchua and Ojobor report indicated that soils with silt/clay ratios below 0.15 indicated that such soils are of old parent material, while those above 0.15 are of young parent materials with low degree of weathering [13]. Lawal et al. recorded silt/clay ratio of ‹ 1.00 in Southern Guinea Savanna soils in Nigeria and concluded that the soils have undergone ferralitic pedogenesis [12]. All the SMUs recorded silt/clay ratios far above unity confirming that the soils are young with weatherable minerals and have not gone through ferralitic pedogenesis.

The SMUs were moderately acidic to neutral, pH (water) ranging from 5.31 to 7.00 for Elemebiri soils, 5.33-6.70 for Odoni soils and 5.30-6.80 for Trofani soils. (Figures 3). The pH of the soils generally increased with soil depth due to less H^+ ions released from organic matter decomposition as organic matter decreased irregularly (Figures 3) with increase in depth [14]. Wong et al. [15] reported pH of 6.0 to 7.0 as the optimum pH for most agricultural crops while [16] and [17] gave 5.5 to 7.0 as the preferred range for most crops. Among the SMUs, the surface layers of ELM1 and ELM2 fall below the FAO preferred pH range.
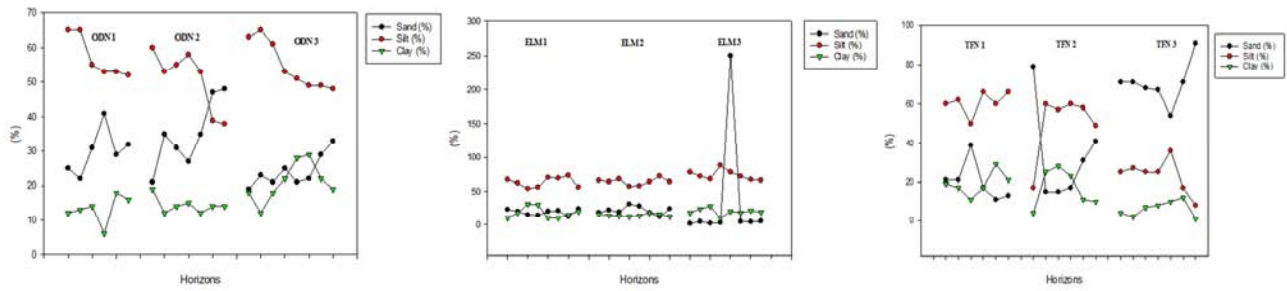
Figure 2. Percent sand, silt and clay in the Odoni (ODN), Elemebiri (ELM) and Trofani (TFN) soils.
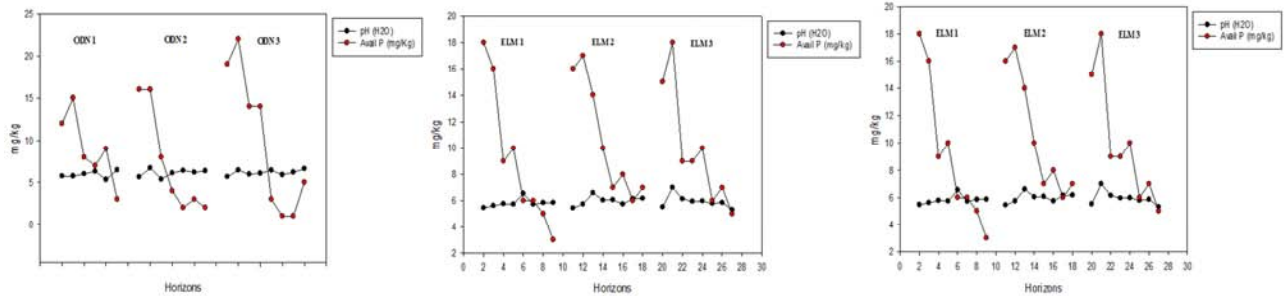

Figure 3. pH and available P distribution in the Odoni (ODN), Elemebiri (ELM) and Trofani (TFN) soils.
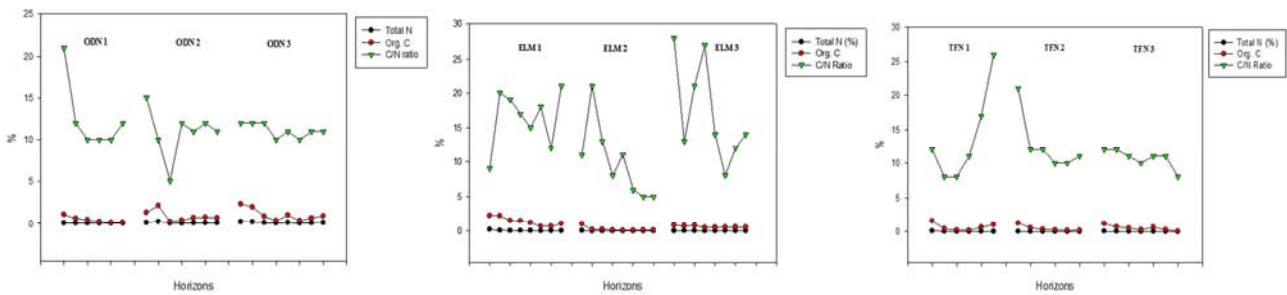

Figure 4. Organic C, total-N and C/N ratio of the Odoni (ODN), Elemebiri (ELM) and Trofani (TFN) soils.
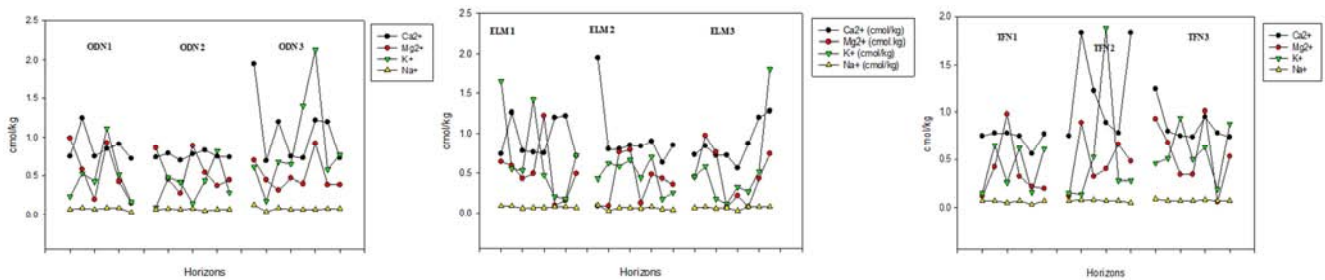

Figure 5. Exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ concentration of Odon (ODN)i, Elemebiri (ELM) and Trofani (TFN) soils.
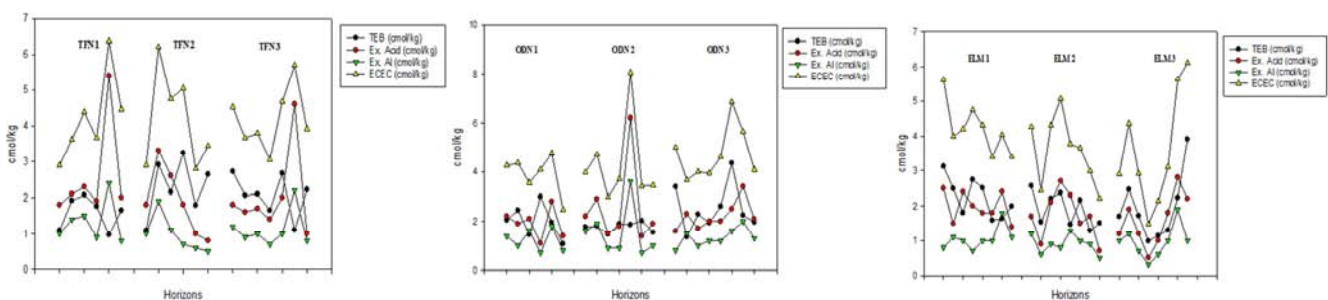

Figure 6. TEB, Exch. Acidity, Exch. Al and ECEC of Odoni (ODN), Elemebiri (ELM) and Trofani (TFN) soils.

This is an indication that the SMUs need some form of soil amendments. Khan et al. attributed increase in soil pH with depth to ferrolysis which is acidification of topsoil caused by continual displacement of bases by ferrous ion during the reduction phase associated with annual flooding [18]. The study area is prone to high rainfall and flooding therefore, there is possibility of ferrolysis. Usually, ΔpH value is used to estimate the presence of negatively charged clay colloids in soils [19]. Positive ΔpH values were obtained for all the soils indicating that the soils were all negatively charged.

Organic matter content of the soils, generally, was low to moderate, ranging from 0.19- 3.88%, 0.13-4.02% and 0.37-2.76% for the Elemebiri, Odoni and Trofani soils, respectively (Figure 4). Generally, organic carbon and indeed organic matter levels decreased irregularly with soil depth which agreed with the reports of previous authors in Nigeria [20-22] in Ethiopia. Khan et al. [17] also reported organic C decrease with soil depth for Bangladeshian soils and low organic C content was attributed to rapid decomposition of organic matter under hyperthermic temperature regime. For the soils under consideration, low organic matter concentration was attributed to low biomass return to the soils owing to short fallow periods coupled with the cultural practice of bush burning which destroys organic materials. It is necessary to note that organic matter mineralization rate in the soils is high due to high temperatures and heavy rainfall as the SMUs belong to the iso-hyperthermic soil temperature regime. Low N values was traced to high rate of organic matter decomposition and mineralization as well as leaching, coupled with intermittent flooding and drying which is known to favour N loss through nitrification-denitrification processes [19]. Hartz reported that soils with less than 0.07% total N have limited N mineralization potential, whereas those having values greater than 0.15% would be expected to mineralize sufficient amount of N during the succeeding crop cycle [23]. Based on this, the surface layers of ELM1, ELM2, ODN2, ODN3, TFN1, and TFN3 are likely to have reasonable mineralization potential while the mineralization potential of ELM3, ODN1 and TFN2 was low.

Exchangeable K varied from 0.18-1.81 cmol/kg in Elemebiri, 0.10-2.13 cmol/kg in Odoni and 0.14-1.88 cmol/kg in the Trofani soils (Figure 5). Also, the ECEC values were low, ranging from 1.49-6.11cmol/kg in Elemebiri soils, 2.47-8.06cmol/kg in Odoni soils, and 2.79-6.37cmol/kg in Trofani Exchangeable Ca^{2+} dominated the exchange complex of the SMUs followed by Mg^{2+}. Cation ratios are helpful in identifying soil structural problems. In the SMUs, Ca^{2+}/Mg^{2+} ratio of most of the layers was above unity. Khan et al. reported Ca^{2+}/Mg^{2+} ratios of less than unity in Bangladeshian soils, attributing this development to loss of Ca^{2+} due to gleization [18]. Boul et al. reported that Ca^{2+}/Mg^{2+} ratio in soils decreases with increasing maturity [14]. The low Ca^{2+}/Mg^{2+} ratios recorded in the SMUs was rather ascribed to the inherently low concentration of ferromagnesian minerals that supply Ca and to a lesser extent, possible loss of Ca by gleization as noted previously by [18]. Low exchangeable bases in soils (Ca, Mg, K and Na) have been attributed to acidifying properties of organic matter, high aluminum concentration and leaching loss of exchangeable bases [24]. The low exchangeable Ca and Mg in these soils was attributed to the inherently low concentration of ferromagnesian minerals, low nutrient retentive capacity, high exchangeable Al and leaching losses due to the high rainfall. Based on the categorization of [17], it is obvious that K in most layers of the pedons was medium to very high

The exchange acidity of 45% of the soils was 2.0cmolkg^{-1} and above suggesting that 45% of the soils were slightly to strongly acidic [25], Odoni soils having higher total exchange acidity.

3.2. Assessing the Fertility Status of the Soil Mapping Units Using SFI and SEF

Figures 7, 8 and 9 showed graphical presentation of the comparison between SFI and SEF of the soil mapping units. The mean SFI values were significantly higher than SEF values ($p < 0.05$) in all the pedons when Turkeys's t-test was used to compare them (Table 2). Among the soil mapping units, the highest SFI value (19.05) was recorded in the surface layer of TFN2 while the lowest value (15.08) was recorded in the bottom layer of ODN2. The highest SEF value (9.87) was recorded in the surface layer of ELM1 and the lowest value (5.85) in the subsurface of ELM2.

Table 2. t-test statistic for paired sample for SFI and SEF.

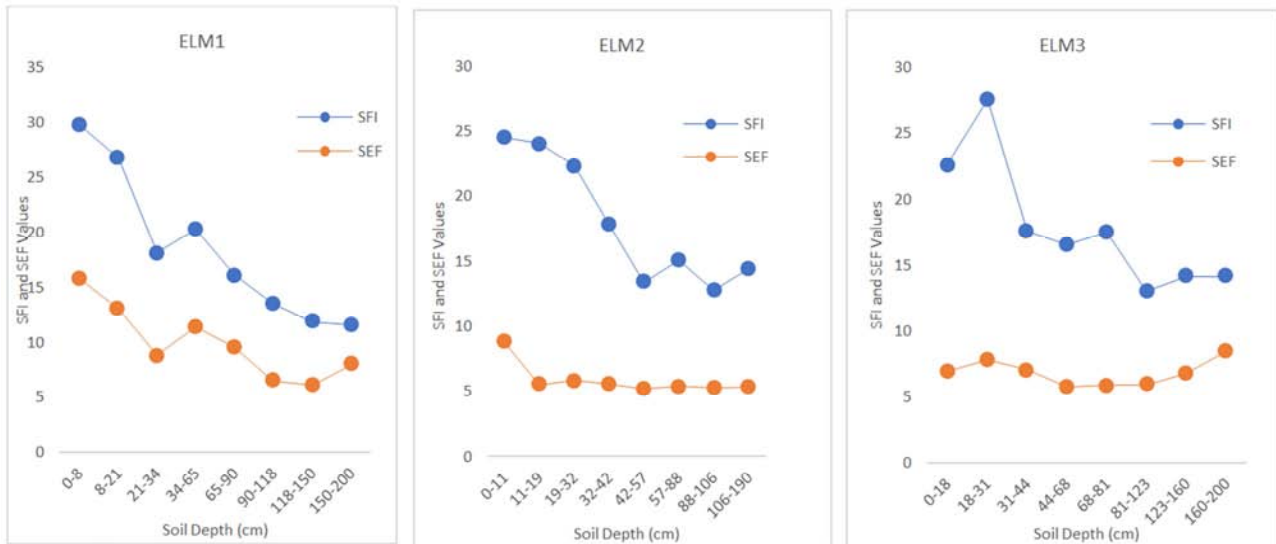| Soil Mapping Unit	Mean SFI	Mean SEF	t-statistic
ELM1	18.48	9.87	6.57*
ELM2	18.02	5.85	8.14*
ELM3	17.85	6.80	6.62*
ODN1	16.35	6.17	6.63*
ODN2	15.08	6.97	3.56*
ODN3	18.94	8.59	3.76*
TFN1	16.46	6.19	5.38*
TFN2	19.05	6.19	5.35*
TFN3	15.72	6.78	5.65*

Figure 7. Comparison of SFI and SEF values with soil depths in Elemebiri soils.
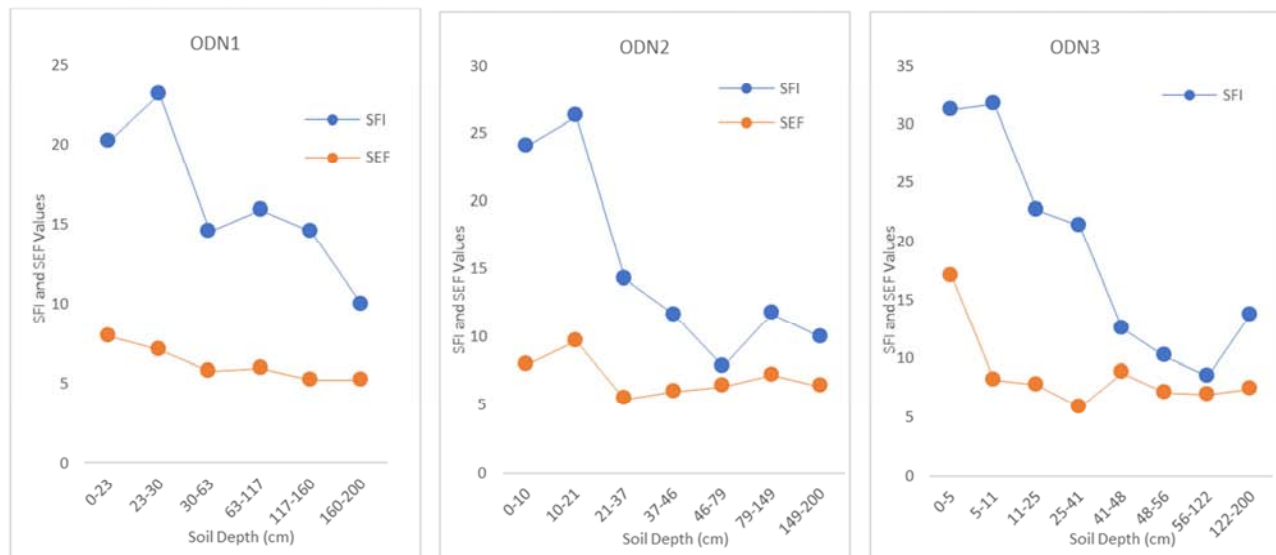

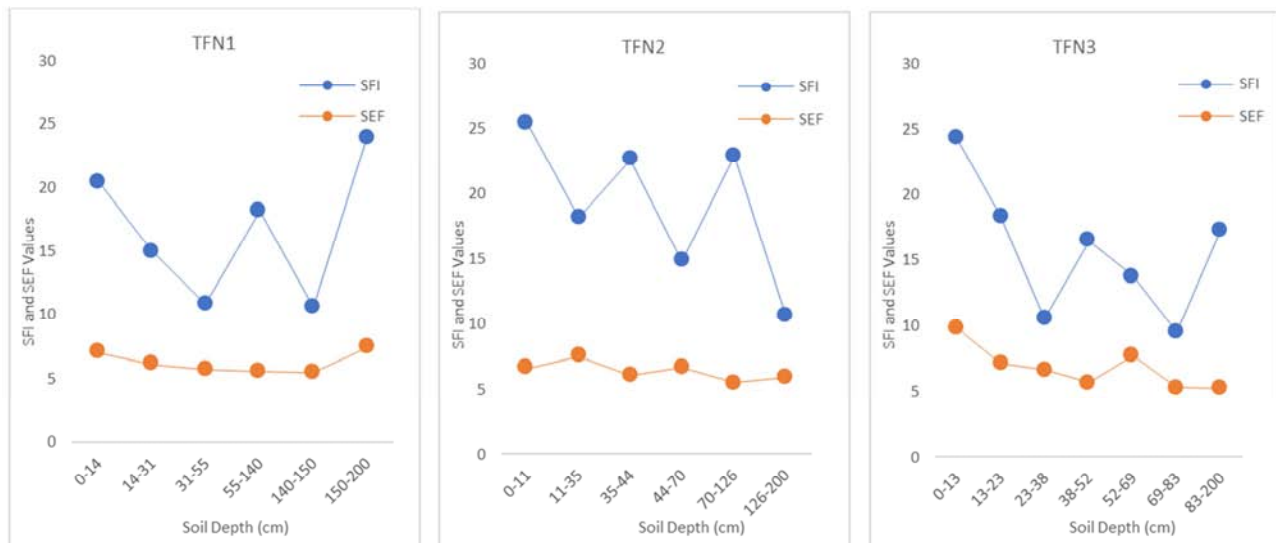*Figure 8.* Comparison of SFI and SEF values with soil depths in Odoni soils.

Figure 9. Comparison of SFI and SEF values with soil depths in Trofani soils.

Higher SFI values were recorded in the soils, contributed by pH, organic matter and phosphorus. Generally, SFI values decreased with increase in depth for all the soil mapping units except in TFN1 where the bottom layers recorded higher SFI values. Higher SFI values in the bottom layers were due to higher concentration of P and fairly high organic matter. SEF values decreased with increased depth in all the mapping units except in ELM3 which was attributed to higher nutrient concentration in the bottom layer. Akbar *et al.* [26, 27] reported higher SFI values in Malaysia and [28] found no significant differences in SFI and SEF values among three soil series under *Khaya ivorensis* plantation and regenerated degraded secondary forests in Malaysia. Akbar *et al.* attributed high SFI values in soils to high organic matter presence and nutrients contents derived from the 'resam' vegetation covering the surface [26]. Aiza *et al.* assessed soil fertility status of rehabilitated degraded tropical rainforest and reported that the highest SEF value was recorded in a soil with high in organic matter and low in exchangeable Al [27]. They also recorded SEF values of less than 5 in rehabilitated and secondary forests which they considered as soils with extremely poor soil fertility as established earlier by [5]. They concluded that vegetation growth contributed very quickly to increase in surface soil fertility, corroborating [7] previous findings. In this study, all horizons in the soil mapping units recorded SEF values of more than 5 (Figures 7-9). Based on the standard of [7], the soils were considered fertile. This is understandable because all the profile pits were sited in fallow areas except ELM3 and TFN3 which are mapping units located on the channels of presently active Niger and Forcados Rivers, respectively. The ELM3 and TFN soils are cultivated every year due to the yearly addition of alluvial materials by the annual floods which improve the fertility level.

4. Conclusion

The high SFI values recorded in the soils were contributed by pH, organic matter and phosphorus which decreased with increase in depth for all the soil mapping units except in TFN1 where the bottom layers recorded higher SFI values. Higher SFI values in the bottom layers were due to higher concentration of P and fairly high organic matter. SEF values decreased with increased depth in all the mapping units except in ELM3 which was attributed to higher nutrient concentration in the bottom layer. In all the mapping units, Biomass accumulation contributed greatly to improvement of soil fertility and physical structure. Therefore, soil organic matter maintenance should be given top priority in these soils for sustained productivity and food security.

References

[1] Mulat, Y., Kibret K., Bedadi, B. & Mohammed, M. 2021. Soil quality evaluation under different land use types in Kersa sub-watershed, eastern Ethiopia. *Environmental Systems Research* 10 (19): 1-11. https://doi.org/10.1186/s40068-021-00224-6.

[2] Ojanuga, A. G., Okusami, T. A. & Lekwa, G. 2003. Wetland soils of Nigeria: status of knowledge and potentials. Soil Science Society of Nigeria Monograph Nigeria. Soil Science Society of Nigeria.

[3] Fasina, A. S. 2008. Irrigation Suitability Evaluation of Asu River Basin Soils, Southeastern Nigeria. *International Journal of Soil Science* 3: 35-41.

[4] Akpan-Idoik, A. U. & Ogbaji, P. O. 2013. Characterization and Classification of Onwu River Floodplain Soils in Cross River State, Nigeria. *International Journal of Agricultural Research* 8: 107-122.

[5] Dickson, A. A. 2018. Characterization, Classification and Suitability E valuation of Agricultural Soils of selected Communities located along various river systems in Bayelsa State, Southern Nigeria.

[6] Sileshi M, Ruben K, Khamaldin M, Stafen S (2019) Determinants for adoption of physical soil and water conservation measures by smallholder farmers in Ethiopia. Int Soil Water Conserv Res. https://doi.org/10.1016/j.iswer.2019.08.002 S.

[7] Lu, D., Moran, E. M. & Mausel, P. 2002. Linking Amazonian secondary succession forest growth to soil properties. *Land Degradation and Development* 13: 331-343.

[8] Dickson, A. A., Tate, J. O., Ogboin, T. P., Cameroon, P. O. William, AP. 2021. Spatial variability of selected soil properties of the lower Niger River floodplain soils in Bayelsa State, Nigeria. *African Journal of Agriculture and Food Science* 4 (3): 14-27.

[9] Moran, E. F., Broodizio, E. S., Tucker, J. M., DA Silva-Forsberg, M. C., Falesh, I. & S. D., M. (eds.) 2000a. *Strategies for Amazonian forest restoration: evidence for afforestation in five regions of the Brazilian Amazon.,* University of London. London: Institute for Latin American Studies, University of London.

[10] Senjobi, B. A. 2007. *Comparative Assessment of the Effect of Land Use and Land Use Type on Soil Degradation and Productivity in Ogun State, Nigeria*. PhD Published Thesis, University of Ibadan, Ibadan.

[11] Senjobi, B. A., Idehen, R. T., Oduntan, O. O. & Adesodun, J. K. 2016. Characterization and morphogenetic variability of soils under-basede oil palm plantations in Southwestern Nigeria. *Journal of Organic Agriculture and Environment* 4: 17-27.

[12] Lawal, B. A., Ojanuga, A. G., Tsado, P. A. & Mohammed, A. 2013. Characterization, classification and agricultural potentials of soils of a toposequence in southern Guinea Savanna of Nigeria. *International Journal of Biology, Veterinary & Food Engineering* 7: 148-152.

[13] Egbuchua, C. N. & Ojobor, S. 2011. Characterization of some hydric soils in the Niger Delta region of Nigeria for land evaluation purposes. *International Journal of Advanced Biological Research* 1: 77-82.

[14] Buol, S. W., Hole, F. D., McCracken, R. J. & Southard, R. J. 2003. *Soil Genesis and Classification*. Iowa State Press.

[15] Wong, J. W. C., Lai, K. M., Su, D. S. & Fang, M. 2001. Availability of heavy metals for Brassica chinensis grown in an acidic loam soil amended with domestic and sewage water. *Water, Air and Soil Pollution* 128: 339-353.

[16] FAO, 2006. *Guidelines for Soil Description.* 4th edition. Food and Agricultural Organization. Rome, Italy.

[17] Brady, N. C. & Weil, R. R. 2005. *The Nature and Properties of Soils*. Pearson Princeton Hills.

[18] Khan, Z. H., Hussain, M. S., & Otter, F. 2005. Morphogenesis of three surface-water gley soils from the Meghna Floodplain of Bangladesh. *Dhaka University Journal of Biological Science* 21: 17-27.

[19] Alemayehu, Y., Gebrekidan, H. & Beyene, S. 2014. Pedological characteristics and classification of soils along landscapes at Abobo, southwestern lowlands of Ethiopia. *Journal of Soil Science and Environmental Management* 5: 72-82.

[20] Idoga, S., & Azagaku, D. E. 2005. Characterization and classification of Janta Area, Plateau State of Nigeria. *Nigeria Journal of Soil Science* 15: 116-122.

[21] Atofarati, S. O., Ewulo, B. S. & Ojeniyi, O. 2012. Characterization and classification of soils on two toposequence at Ile-Oluji, Ondo State, Nigeria. *International Journal of Agricultural Science* 2: 642-650.

[22] Abate, N., Kibret, K., Gibrekidan, H. & Esayas, A. 2014. Characterization and classification of soils along the toposequence at the Wadla Delanta Massif, North Central Highlands of Ethiopia. *Journal of Ecology and the Natural Environment*. 6: 304-320.

[23] Hartz, T. 2007. Soil Testing for Nutrient Availability: Procedures and Interpretation for Carlifornia Vegetable Crop Production. University of Carlifornia, Davis. Department of Plant Sciences, Vegetable Research and Information Center. 1-7p.

[24] Tisdale, S. L., Nelson, W. L., Beaton, J. D. & Havlin, J. L. 2004. *Soil Fertility and Fertilizers*. Prentice Hall of India private Limited, New Delhi, India.

[25] Ernest, C. I. & Onweremadu, E. U. J. 2016. Classification of soils along Ogochie River Floodplain in Ngor-Okpala, Imo State, Southeastern Nigeria. *Journal of Global Research* 2: 78-83.

[26] Akbar, M. H., Ahmed, O. H., Jamaluddin, A. S., Majid, N. M. & Abdul-Hamid, H. 2010. Differences in soil physical and chemical properties of rehabilitated and secondary forests. *American Journal of Applied Science* 7: 1200-1209.

[27] Aiza, S. J., Arifin, A., Hazandy, A., Mohd, H. A., Trevor, S. B. Shamshuddin, J. & Nik, N. M. 2013. Assessing Soil Fertility Status of Rehabilitated Degraded Tropical Rainforest. *Environment Science* 9: 280-291.

[28] Yeti, H., Arifin, A., Mohd, N. M., Hazandy, A., Shanshuddin, J., Nik, N. M., Ika, H., Leslie, A. & Khairulmazmi, A. 2011. Comparing the Fertility of Soils under Khaya ivorensis Plantation and Regenerated Degraded Secondary Forests. *American Journal of Applied Science* 8: 472-480.