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Soil Physical Fertility Status and Management Prescription for Soil Sustaining Farms and Ranches in Abuja, Nigeria

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Abstract: Physical soil fertility is seldom emphasized beyond particle size distribution in soil fertility studies. A study assessed the soil physical fertility status of a Typic Plinthustalfs sustaining farms and ranches in Abuja, the Federal Capital Territory of Nigeria. The main objective of the study was to measure the soil physical properties and prescribe soil husbandry practice for sustainable management of the soils. Soil samples were collected from eleven fields cultivated to pasture crops. The samples were processed and analyzed for particle size distribution (PSD), bulk density, soil organic carbon (SOC), saturated hydraulic conductivity (SHC), soil pH, clay flocculation index (CFI), field capacity (FC) and permanent wilting point (PWP). Total porosity and soil organic matter (SOM) was inferred from bulk density and SOC, respectively. All the cultivated fields were sandy loam in texture with predominantly sand fractions (sand > 700 g kg^{-1}). The porosity values were 45 % fitting the field into "satisfactory soil" class for crop production. The pH ranged from 5.9 to 6.2. The CFI revealed the soils micro-stability are low ≤ 43 %. The FC was low and ranged from 13 to 15 %, this is against standard values of 15 to 25 % for sandy soils. This implies crop in the field will readily suffer from incipient wilting. The SHC ranged from 6.5 to 8 cm hr^{-1} putting the soil in the "moderately rapid" conductivity class. The SOC and SOM were rated as low for tropical soils. With predominantly sand in the soil, low SOM and moderately rapid SHC, the retention of water and applied plant nutrients will be a challenge. Mulching and recycling of processed farmyard manure and other ruminant waste that abound on the farm should be a practice. The organic inputs will help rebuild the soil structure, improve soil water and plant nutrient retention.

Keywords: Soil physical fertility, soil physical property, cultivated Typic Plinthustalfs, soil management, soil porosity.

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1. Introduction

In the quest to increase crop yields and achieve food security (SDG 2) and alleviate poverty (SDG 1), governments in Africa puts policy emphases on fertilizer production and impor (Bonilla Cedrez et al., 2020; Ciceri and Allanore, 2019; Gil et al., 2019; McGowan et al., 2019). This is because crop production and soil productivity were majorly linked to chemical fertility of the soil. In the past, the contributions of soil physical properties to plant growth was not given the recognition it deserves in soil fertility studies (Adjei-Nsiah, 2019; Schjoerring et al., 2019; Stewart et al., 2019; Yadav and Soni, 2019). Recently, there seems to be growing recognition that yields are also limited by physical conditions rather than only chemical status of the soil (Carciochi et al., 2020; Liu et al., 2015; Oku et al., 2015). It is known that chemical and biological processes in the soil that work to enhance the soil and crop productivity operates on the foundation laid by soil "physical block" (Mangi et al., 2018). The particle size fraction of the soil can be referred to as "soil skeleton". The role as a "skeleton" can be likened to the supporting role of the skeleton of the human body. It holds in place water and supply same

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water to plants and other organisms in the soil (Kelting et al., 1999; Schoenholtz et al., 2000). Additionally, the "soil skeleton" provides an environment for biological activities in the soil and sequester carbon. Plants require water for its growth and field performance such as the yield. Whereas, the water holding capacity of the soil is tied to the particle size fraction and organic matter content, the retention of water in the soil for plant use and growth is governed by the soil water potential (Letey, 1991).

The soil organic carbon (SOC) is an important makeup of the soil structure and a major determinant of soil productivity. The building up of soil organic matter (SOM) is linked with the SOC, soil moisture, soil temperature as well as vegetation and land use (Pendall et al., 2004). It has been reported that for Ultisols, Alfisols as well as Oxisols that soil organic carbon (SOC) values of ≤ 1 % (low) will have a strong negative impact on soil productivity (Anue and Lal, 1997). The severity of both wind and water erosion on a soil is governed by the physical condition of the soil such as particle size, bulk density or compaction, aggregate stability among others. The ease of root penetration into the soil, promotion of root growth, geochemical processes in the soil are tied to the soil physical condition. Soil bulk density controls pore spaces available for water and air in the soil, infiltration of water within the rooting zone of plants (Oku et al., 2015; Almendro-Candel et al., 2018). A soil with a good structure allows adequate entry of air and water into the soil and control its circulation for healthy plant growth. Without some physical properties, existing at optimum level in the soil, the soil will suffer from anaerobic condition, waterlogging and plant nutrients will be locked up. With high bulk density plants will either be unable to penetrate such soils or will die as a result of inability to take up nutrients. The ability of the soil to retain water and nutrients is critical for crop production and this relates to SOM and soil structural properties. Soils with high bulk density will have poor infiltration rate and high runoff. Aside, washing away carbon, and essential plant nutrients, runoff will induce negative changes in soil chemical and physical properties (Oku and Babalola, 2009). Therefore, the specific objectives of the study were to: (1) quantify the soil physical properties within the farms and ranches, (2) compare the field measured values with soil physical fertility standards required for tropical soils and (3) prescribe soil husbandry practices that would rebuild the soil fertility over time and restore soil productivity.

2. Materials and Methods

The study was conducted during the dry season of late 2019 within a land sustaining Farms and Ranches in Abuja, the Federal Capital Territory (FCT) of Nigeria as in Fig. 1.

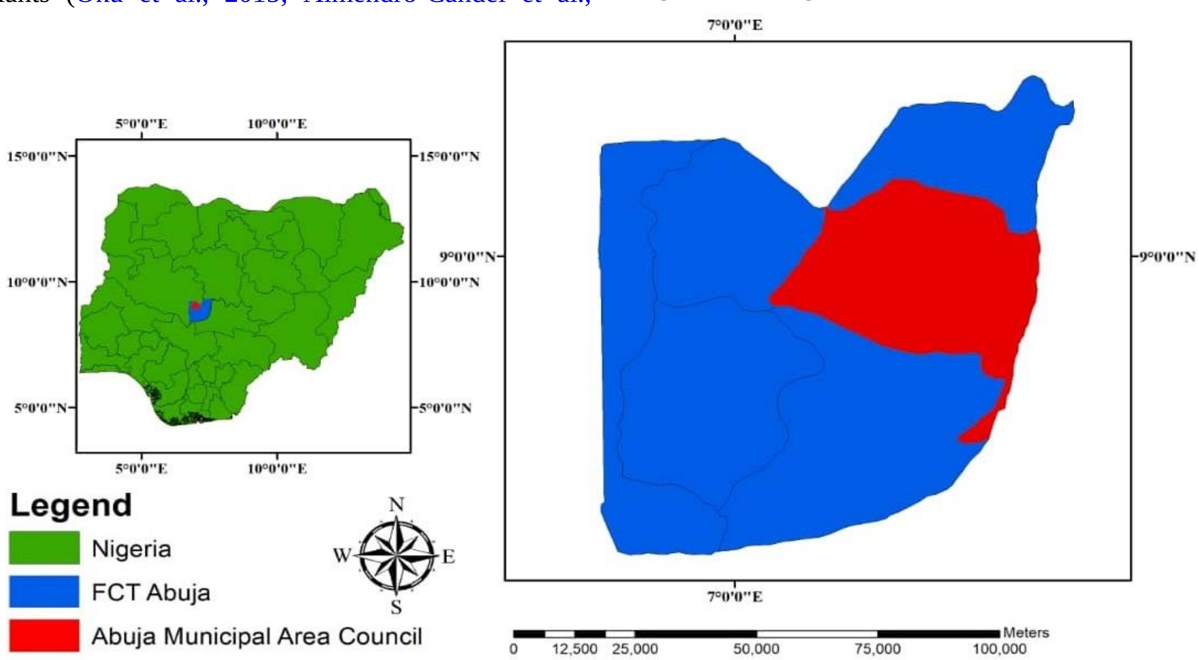

Fig. 1. Location of the study area in Nigeria, West Africa

Table 1. Ratings for interpreting selected soil properties for tropical soils

Parameter	Range / Rating		Source
Organic matter (%)	Low	< 2	Udo et al., (2009)
	Moderate	2 - 3	
	High	> 3	
	Very High	> 6	
Porosity (%)	Poor agricultural soils	< 40	Kachinskii, (1970)
	Satisfactory agricultural soil	41 - 45	
	Good agricultural soils	46 - 50	
	Best agricultural soils	> 50	
Coefficient of variability (%)	Low	< 15	Wildings, (1985)
	Moderate	16 - 35	
	High	> 35	
Saturated hydraulic conductivity (cm/hr)	,0.8	Very slow	FAO, (1963)
	0.8 – 2	Slow	
	2.1 – 6.00	Moderately slow	
	6.1 – 8.00	Moderately rapid	
	8.1 – 12.50	Rapid	
	> 12.50	Very rapid	
Organic carbon (%)	< 1	Low	Udo et al., 2009
	1 – 1.5	Moderate	
	> 1.5	High	

The FCT falls within the Southern Guinean Savanna zone of the West Africa. The soils of Abuja are classified as Alfisols and sub order of Ustalfs with Ustic moisture regime, a characteristic of the sub humid climate regime. There is a dominant occurrence of plinthite layers or continuous concretionary layers precisely within 24 cm and 39 cm and at times 150 cm depth. At the great-order group of Plinthustalfs, another sub-group as Typic Plinthustalfs exist (Lawal et al., 2012). Soils of Abuja are underlain predominantly by basement complex rocks dominated by granites, gneisses, migmatites, quartzites and schist. (Bennett et al., 1979). This gives rise to a wide variety of soils. The upland soils under the basement complex formation are generally deep, weakly to moderately structured, sand to sandy clay in texture with gravel and concretionary layers in the upper or beneath the surface layers (Ojanuga, 2006). Quartz is observed to be the prominent mineral constituents of the soils with high kaolinite clay content which is responsible for the relatively low plasticity of the soils (Alhassan et al., 2012). The weather of FCT includes a warm, humid, rainy season and a scorching dry season. The highest annual rainfall within the Territory, is about 1632 mm. It records relative humidity in the dry season, goes as high as 20 % in the afternoons at the northern high elevations and about 30 % in the extreme south.

The Farm was stratified into eleven fields according to land use, stage of vegetation and landform. Eleven fields cultivated to pasture crops within the farms and ranches were sampled to investigate the soil hydro-physical properties. Undisturbed core samples were collected at a depth of 0–30 cm from randomly selected positions in the different fields using a cylindrical core of 30 cm in length. The samples were bulked to get composite samples for each land use. Particle size analysis (PSA) was done using the hydrometer method (Gee and Bauder, 1986). Bulk density was determined by the core method (Burke et al., 1986). Porosity was calculated as the function of total volume not occupied by soil solids, assuming a particle density of 2.65 Mg m^{-3} (Danielson and Sutherland, 1986) Soil organic matter (SOM) content was calculated using the function given below.

Clay Flocculation Index (CFI) = $\frac{T(c) - WD(c)}{Clay} \times 100$ as used by Igwe, and Udegbunam, (2008)

Where $WD_{(Si)}$ = Water dispersed silt value
$WD_{(c)}$ = Water displaced clay value
$T_{(c)}$ = Total clay value

Soil pH was determined (1:2.5 soil, water suspension) using the pH meter (IITA, 1982). Soil organic carbon was determined by the wet oxidation method (Nelson and Sommers, 1982). Percentage (%) SOM = % organic carbon×1.724 (Walkley, 1934). The parameters determined were compared with standard ratings for tropical soil presented in Table 1.

3. Results and Discussion

Table 2 shows the particle size distribution (PSD) in eleven fields within the farms and ranches studied. The soil in all the cultivated fields sampled are sand (> 700 g kg^{-1} of soil). The silt fraction ranged from 81 g kg^{-1} to 186 g kg^{-1}, clay proportion ranged from 62 g kg^{-1} to 86 g kg^{-1}. The texture was predominantly loamy sand. With the predominant sand fraction, the specific surface area of the soil is small.

This implies that, the site for exchange of cation is equally small. It is expected that the cation exchange capacity of the soil will be low (Oku and Edicha, 2009). The retention of plant nutrients and water in the soil for crop growth will be a challenge. The dominance of sand in the soil is one indicator of poor aggregate state of the soil. This implies the soil will be readily detached on receiving erosive downpour (rainfall) (Oku and Babalola, 2009). However, the transportation of the detached soil sediment will be low because of the large particle diameter typical of sand fractions. The pH in water of the fields ranged from 5.9 to 6.2 as in Table 3. This indicates the soils are between moderately acidic and slightly acidic (Udo et al., 2009). A difference existed between pH in water and pH in KCl indicating the potentials for cation exchange if the soils are amended with inputs particularly of organic origin (McCauley et al., 2009).

The SOC values and the clay fractions obtained in the study were lower than those reported by Adeboye et al. (2009) and Alhassan et al. (2012) for similar soils in the same agroecological zone. This could be attributed to the de-surfacing of the native surface soils in the area for the establishment of the farms and ranch.

Table 2. Particle Size Distribution (PSD) of a Farm and Ranch in Abuja, Nigeria

Pasture Field	Sand	Silt	Clay	Texture
	g kg^{-1}			
1	744	186	70	Sandy loam
2	810	108	82	loamy sand
3	770	144	86	Sandy loam
4	788	130	82	loamy sand
5	814	118	68	loamy sand
6	804	134	62	loamy sand
7	794	132	74	loamy sand
8	840	81	79	loamy sand
9	794	138	68	loamy sand
10	784	140	76	loamy sand
11	774	152	74	loamy sand
Mean	792	133	75	
CV %	3	20	10	

Table 3. Soil pH and organic carbon content of a Farm and Ranch in Abuja, Nigeria

Pasture Field	pH in water	pH in KCl	OC	SOM
			g kg^{-1}	
1	6.10	5.80	9.00	15.66
2	6.20	5.80	9.20	16.00
3	6.00	5.60	9.50	16.53
4	5.30	5.00	10.20	17.70
5	6.00	5.60	7.80	13.57
6	6.10	5.70	9.40	16.35
7	6.00	5.50	9.40	16.36
8	5.90	5.30	8.80	15.31
9	6.20	5.70	9.20	16.00
10	5.90	5.40	10.80	18.79
11	6.10	5.50	8.80	15.31
Mean	6	5.5	9.28	16.14
CV %	4	4	10	10

Table 4 shows some structural and hydrological properties determined. Bulk density gives a fair idea of the extent of compaction of a soil. The total soil porosity inferred from bulk density indicates the soils fall into the "satisfactory agricultural" class (porosity = 41 to 45 %) using Kachenskii, (1970) rating for tropical soils. This is expected as the fields were ploughed and harrowed before the planting of pasture crops. The clay flocculation index (CFI) is one of the indices used in assessing micro-aggregate stability of agricultural soils. The higher the CFI values the higher the stability of the soil to erosion. The CFI values were low ≤ 43 %, except in one field where the value of 63 % was recorded. The FC ranged from 13 to 15 %. This is considered low as sandy soils are expected to possess FC values of 15 to 25 % and loam soils 35 to 45 % (Cornell University, 2018).

Permanent wilting point (PWP) of the soils as presented in Table 4, lies between 6 and 7 % of the soil volume. Sandy soils and loamy soils are expected to have PWP of 10 to 15 % and 15 to 20 %, respectively (Cornell University, 2018). This indicates planted crops will suffer frequently from incipient wilting and would enter permanent wilting stage under a short dry spell or delayed irrigation. Initial wilting is likely to cause reduction in the yields of crops and pastures. The saturated hydraulic conductivity (SHC) of the soils ranged from 6.5 to 8 cm h^{-1} (Table 4). With this SHC values, the soils fall into the "moderately rapid conductivity class (FAO, 1963). With this conductivity rating and the predominant sand fraction as shown in Table 2, plant nutrients applied in the form of inorganic fertilizers will flow down the soil fast beyond crop rooting zones.

This SHC class combined with the coarse nature of the soil is likely to create a moisture stress condition in the soil when the atmosphere is dry, relative humidity low and evaporative demand of the atmosphere is high (Dorner et al., 2010; Gwenzi et al., 2011). Abundant application of processed farmyard manure improves aggregation of the soil as well as retention of water and nutrients in the soil for crop uptake (Eden et al., 2017; Paradelo et al., 2019; Sharma et al., 2019). Split application of inorganic fertilizer would be the best practice. Split fertilizer application potentially reduce nutrient losses per fertilizer application and increase plant nutrient uptake (Jiang et al., 2018; Sitthaphanit et al., 2009).

Table 4. Some structural and hydrological properties of a Farm and Ranch in Abuja, Nigeria

Pasture Field	Bulk density	Porosity	CFI	FC	PWP	SHC
	$g\ cm^{-3}$	%	%	% Vol		$cm\ hr^{-1}$
1	1.45	45	21	14	6	745
2	1.45	45	40	13	7	7.26
3	1.46	45	43	15	7	6.55
4	1.45	45	40	14	7	7.35
5	1.45	45	28	13	6	8.25
6	1.44	46	63	13	6	8.87
7	1.45	45	34	13	6	8.02
8	1.45	45	38	13	7	7.88
9	1.45	45	28	13	6	8.02
10	1.45	45	36	14	7	7.558
11	1.45	45	26	14	6	7.79
Mean	1.50	45.10	36	13.6	6.5	7.73
CV %	0.31	0.67	32	5.28	7.06	7.79

3.1. Prescribed soil husbandry for improving the soil physical fertility in relation to crop production

The "engine of the soil" (soil structure) is poor and weak and require large organic inputs to rebuild the soil structure. At the same time the native soil fertility is low and requires a large amount of macro and micro nutrients to give meaningful crop yield. Therefore, integrated nutrient management should be the practice in the farm. Cropping systems that include cover crops, soil re-building and water conservation crops as legumes should be included. The farm produces large quantity of cow-dung aside other ruminant animal waste. The waste should be processed and recycled to improve the SOC and SOM.

The increase in SOM will cause aggregation of sand that in turn will improve the water and plant nutrient retention capacity of the soil. High SOM will lead to an increase in the buffering of soil pH against fluctuations. Though the bulk density and the total porosity are "satisfactory" for crop production, organic inputs into the soil will further reduce the bulk density and increase the porosity shifting the soil into "good agricultural soil" (porosity ≥ 46 to 50 %) and "best agricultural soil" (porosity > 50 %). Organic inputs will further improve both the macro and micro stability of the soil. Mulching of the soil surface is a recommended practice to reduce evaporation of water from the soil surface and for conservation of water in the soil for crop use.

4. Conclusion

The continuous tillage gives soil porosity values that make the soil "satisfactory" for crops and pasture crop production. However, the "soil skeleton" (particle size dominated sand fractions) indicates that soil has little "flesh" covering the skeleton and requires management practices that would promote accumulation of more "flesh". The SOM, content of the soil also indicates the "soil engine" (structure) is weak, therefore, will be unable to sustain crop production for a long time without heavy external inputs. Inputs to be applied should include organic materials to increase soil biological activities, improve the soil structure, soil aeration as well as retention of nutrients for good plant performance. There is a critical need to increase the SOM content of the soils by incorporation of well processed farmyard manure abundantly produced on the farm and ranch.

List of Abbreviations: PSA – particle size analysis, PSD – particle size distribution, SOC: soil organic carbon; SOM: soil organic matter; CFI, clay flocculation index; FC: field capacity; PWP: permanent wilting point; SHC: saturated hydraulic conductivity.

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Author's Contribution: E. E. Oku and N.C. Odoh designed and supervised the field study. S.N. Emmanuel collected field data and worked with M.I. Barnabas in the laboratory. All the authors contributed to the writing of the paper and read through the paper.

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References

Adeboye, M.K.A., A.O. Osunde., M.I.S. Ezenwa, A. J. Odofin and A. Bala. 2009. Evaluation of the fertility status and suitability of some soils for arable cropping in the southern Guinea savanna of Nigeria. Nigerian J. Soil Sci. 19 (2): 115-120.

Adjei-Nsiah, S. 2019. Integrated Soil Fertility Management Options for Sustainable Intensification in Maize-Based Farming Systems in Ghana. In: Panpatte, D.G., Jhala, Y.K. (Eds.), Soil Fertility Management for Sustainable Development. Springer Singapore, Singapore, p. 291-303.

Alhassan, M., E. Mesaiyete and A.M. Mustapha. 2012. Clay mineralogy of lateritic soils derived from granite basement-a case study of Minna lateritic soils. J. Geotechn. Engg. 17: 1897-1903.

Almendro-Candel, M., L. Gomez, N.J. Ignacio and A. Zorpas 2018. Physical properties of soils affected by the use of agricultural waste. In: Aladjadjiyan, A. (Ed), Agricultural Waste and Residues. IntechOpen Limited, UK. 10 -27.

Aune, J.B. and R. Lal. 1997. The tropical soil productivity calculator Đ a model for assessing effects of soil management on productivity. In: Lal, R., Stewart, B.A. (Eds.), Soil Management Experimental Basis for Sustainability and Environmental Quality. Advances in Soil Science, Lewis Publishers, London, UK. 499 -520.

Bennett, J.G., A.B. Rains, P.N. Gosen, W.S. Howard, A.A. Hutchineon, W.B. Kerr, J.E. Mansfield, L.R. Rackhan and R.R. Innes. 1979. Land resources of central Nigeria. Agric. Dev. Possibilities. The Kaduna Plains. LRD, Tolworth Tower, Survey, England. 58: 130.

Bonilla Cedrez, C., J. Chamberlin, Z. Guo and R.J. Hijmans. 2020. Spatial variation in fertilizer prices in Sub-Saharan Africa. PLOS ONE. 15(1): e0227764.

Burke, W. and L.E. Sommers. 1986. Soil structure assessment. Balkema A. A. Rotterdam.

Carciochi, W.D., V.O. Sadras, A. Pagani and I.A. Ciampitti. 2020. Co-limitation and stoichiometry capture the interacting effects of nitrogen and sulfur on maize yield and nutrient use efficiency. European J. Agron. 113: 125973.

Ciceri, D. and A. Allanore. 2019. Local fertilizers to achieve food self-sufficiency in Africa. Sci. Total Environ. 648: 669-680.

Cornell University. 2018. Northeast Region Certified Crop Adviser (NRCCA) Study Resources. Cornell University Publication. https://nrcca.cals.cornell.edu/soil/CA2/CA0212.1-3.php (Retrieved November 20, 2019)

Danielson, R.E. and P.L. Sutherland. 1986. Methods of soil analysis. Porosity. In: Klute, A. (ed.). 2nd edition. Madison: American Society of Agronomy. 1: 443-461.

Dörner, J., D. Dec, X. Peng and R. Horn. 2010. Effect of land use change on the dynamic behaviour of structural properties of an Andisol in southern Chile under saturated and unsaturated hydraulic conditions. Geoderma. 159(1): 189-197.

Eden, M., H.H. Gerke and S. Houot. 2017. Organic waste recycling in agriculture and related effects on soil water retention and plant available water: a review. Agron. Sustain. Develop. 37(2): 11.

Essoka, A.N. and E.E. Oku. 2015. Physical properties and management of forested steep lands being converted to farmlands: the case of Oban hills, Cross River State, Nigeria. J. Agric. Vet. Sci. 8 (2): 71 – 75.

FAO. 1963. Highdams soil survey project. Deb. BC. Rome.

Gee, G.N. and J.W. Bauder. 1986. Particle size distribution. p 383–411. In: A Klute (ed.). 2nd ed. Methods of Soil Analysis Part 1. Physical and Mineralogical Methods. Madison, Wisconsin.

Gil, J.D.B., P. Reidsma, K. Giller, L. Todman, A. Whitmore and M. van Ittersum. 2019. Sustainable development goal 2: Improved targets and indicators for agriculture and food security. Ambio. 48(7): 685-698.

Gwenzi, W., C. Hinz, K. Holmes, I.R. Phillips and I.J. Mullins. 2011. Field-scale spatial variability of saturated hydraulic conductivity on a recently constructed artificial ecosystem. Geoderma. 166(1): 43-56.

Igwe, C.A. and O.N. Udegbunam. 2008. Soil properties influencing water-dispersible clay and silt in an Ultisol in southern Nigeria. Int. Agrophys. 22: 319-325.

IITA (International Institute for Tropical Agriculture) 1982. Selected methods for soil and plants analysis. Manual series No. 7. IITA Ibadan, Nigeria.

Jiang, C., D. Lu, C. Zu, J. Zhou and H. Wang. 2018. Root-zone fertilization improves crop yields and minimizes nitrogen loss in summer maize in China. Sci. Rep. 8(1): 15139.

Kelting, D.L., J.A. Burger, S.C. Patterson, W.M. Aust, M. Miwa and C.C. Trettin, 1999. Soil quality assessment in domesticated forests Đ a southern pine example. Forest Ecol. Manag. 122: 167 - 185.

Lawal, B.A., M.K.A. Adeboye, P.A. Tsado, M. . Elebiyo and C.R. Nwajoku, 2012. Properties, classification and agricultural potentials of lateritic soils of Minna in sub-humid agroecological zone, Nigeria. Int. J. Devel. Sustain. 1(3): 903-911.

Letey, J. 1991. The study of soil structure-science or art. Aust. J. Soil Res. 29 (6): 699-707.

Liu, Y., X. Pan and J. Li. 2015. A 1961–2010 record of fertilizer use, pesticide application and cereal yields: a review. Agron. Sustain. Develop. 35(1): 83-93.

Mangi, L.J., 1. Bijay-Singh, C.M. Stirling, H.S. Jat, J.P. Tetarwal, R.K. Jat, R. Singhk, S. Lopez-Ridaura and P.B. Shirsath. 2018. Soil processes and wheat cropping under emerging climate change scenarios in South Asia. Adv. Agron. 148: 111 -171.

McCauley, A., C. Jones and J. Jacobsen. 2009. Soil pH and organic matter. Nutrient Management Module. 8(2): 1-12.

McGowan, P.J.K., G.B. Stewart, G. Long and M.J. Grainger. 2019. An imperfect vision of indivisibility in the Sustainable Development Goals. Nat. Sustain. 2(1): 43-45.

Nelson, D.W. and L.E. Sommer.1982 Organic carbon. Methods of soil analysis. Part 2. Agronomy Monograph9. Agronomy Society of America, Madison. 570 – 571.

Ojanuga, A.G. 2006. Agroecological Zones of Nigeria Manual. FAO/NSPFS, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria. p: 124.

Oku, E. E., T. Ojikpong, A. Yakubu, and P. Ezeaku. 2015. Soil carbon dynamics and soil properties influenced by different types of agronomic land use in the forest zone of Nigeria. J. Environ. Agric. Sci. 2: 1-5.

Oku, E.E and J. Edicha. 2009. The physical properties of some soil profiles and management of an erosion prone soil in southwestern Nigeria. J. Agric. Forest. Soc. Sci. 7 (1): 180 –190.

Oku, E.E and O. Babalola. 2009. Effects of down slope distance on primary particle size fraction and physical parameters in erosion prom southwestern Nigeria. J. Soil Water Cons. 8(2): 21 – 24.

Paradelo, R., M. Eden, I. Martínez, T. Keller and S. Houot. 2019. Soil physical properties of a Luvisol developed on loess after 15 years of amendment with compost. Soil Till. Res. 191: 207-215.

Pendall, E., S. Bridgham, P.J. Hanson, B. Hungate, D. W. Kicklighter, D.W. Johnson, B.E. Law, Y. Luo, J. P. Megonigal, M. Olsrud, M. G. Ryan and S. Wan, 2004. Below-ground process responses to elevated CO2 and temperature: a discussion of observations, measurement methods, and models. New Phytol. 16: 311–322.

Schjoerring, J.K., I. Cakmak and P.J. White. 2019. Plant nutrition and soil fertility: synergies for acquiring global green growth and sustainable development. Plant Soil. 434(1): 1-6.

Schoenholtz, S.H., H.V. Miegroet and J.A. Burger. 2000. A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities. Forest Ecol. Manag. 138: 335 – 356

Sharma, B., B. Vaish, Monika, U.K. Singh, P. Singh and R.P. Singh. 2019. Recycling of Organic Wastes in Agriculture: An Environmental Perspective. Int. J. Environ. Res. 13(2): 409-429.

Sitthaphanit, S., V. Limpinuntana, B. Toomsan, S. Panchaban and R.W. Bell. 2009. Fertiliser strategies for improved nutrient use efficiency on sandy soils in high rainfall regimes. Nutr. Cycl. Agroecosyst. 85(2): 123-139.

Stewart, Z.P., G.M. Pierzynski, B.J. Middendorf and P.V.V. Prasad. 2019. Approaches to improve soil fertility in sub-Saharan Africa. J. Exp. Bot. 71(2): 632-641.

Udo, E.J., T.O. Ibia, J.A. Ogunwale, A.O. Ano, and I. E. Esu. 2009. Manual of soil, plant and water analysis. Lagos: Sibon Books, Publishers Limited., Nigeria.p: 183.

Walkley, A.J. and I.A. Black.1934. Estimation of soil organic carbon by the chromic acid titration method. Soil Sci. 37: 29-38.

Wilding, L.P. 1985. Spatial variability: its documentation, accommodation and implication to soil surveys, pp. 166-194. In D.R. Nielsen and J. Bouma (eds.). Soil Spatial Variability: Pudoc, Wageningen, Netherlands.

Yadav, S.K. and R. Soni. 2019. Integrated Soil Fertility Management. In: Panpatte, D.G., Jhala, Y.K. (Eds.), Soil Fertility Management for Sustainable Development. Springer Singapore, Singapore, pp. 71-80.