International Journal of Innovative Agriculture & Biology Research 9(4):28-39, Oct.-Dec., 2021

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Determination of Physical And Chemical Properties Of Soils For Agriculture In Southern Guinea Savanna Zone Of Nigeria

Oyetola, S.O., Agber, P.I. & Ali, A.

Department of Soil Science,
University of Agriculture, P.M.B. 2373, Makurdi, Nigeria

ABSTRACT

Field experiments were carried out during the 2017 and 2018 cropping seasons to determine the physical and chemical properties of selected upland soils for agriculture in the Southern Guinea Savanna zone of Nigeria. Four locations within Southern Guinea Savanna zone of Nigeria namely Abuja (Latitude 9.0764785'N and longitude: 7.398574'E), Minna (Latitude 9.5035546'N and longitude 6.5463156'E), Lafia (Latitude 8.502676'N and longitude 8.522670'E) and Makurdi (Latitude 7°46' – 7°50'N and Longitude 8°36' – 8°40'E) were used for the experiment. A total of 36 soil composite auger samples were collected from cropped fields at three depths, viz: 0 – 15 cm, 15 – 30 cm and 30 – 45 cm for physical and chemical analysis across the four locations and subjected to fertility related parameters. The results of the study showed that the study sites were slightly acidic, low to moderate macronutrients, high micronutrients with sandy loam texture. The texture of soils showed an irregular decreasing trend with sandy loam > sandy silt loam >sandy clay. The soil nutrients indicated varied changes in contents with respect to soil depths. The values of permeability, bulk density, hydraulic conductivity, soil pH, organic matter, CEC, N, P and exchangeable bases decreased with increase in soil depth while porosity and water holding capacity of the soils increased with increase in soil depths.

Keywords: Soil properties, fertility, upland soils, macronutrients, micronutrients

INTRODUCTION

One of the major challenges facing Nigeria in her quest to achieve food security is the vast degrading agricultural lands. In addition to soil degradation caused by natural elements, there has been consistent decline in soil productivity because of intense cultivation and poor soil management strategies across the nation. Successful agriculture requires the sustainable use of soil resource because soils can easily lose their quality and quantity within a short period for many reasons. Soils through land use change produce considerable alterations (Yakubu, 2010) while soil quantity diminishes after the cultivation of previously untilled soil (Neris *et al*., 2012). Agricultural practice requires basic knowledge and assessment of charges in soil properties and hence their status with time to evaluate the impact of different management practices.

Soil properties (physical, chemical and biological) affect many processes in the soil that make it suitable for agricultural practices and other purposes. Assessing soil quality involves measuring soil properties and using the measured values to detect changes in soil as a result of land use or management practices The dynamic soil nature describes the condition of a specific soil due to land use and management practices. According to Wang *et al*., (2001), climate and geological history are importance factors which affect soil properties on regional and continental scales. However, under small catchment scale, land use may be the dominant factor affecting soil properties. Land use and soil management practices influence the soil nutrients and related soil processes, such as erosion oxidation mineralization and leaching (Liu *et al*., 2010). As a result, it can modify the processes of transport and redist4ibution of nutrients.

Changes in soil properties due to management practice and their consequence to the environment as well as their production capacity have be studied (Jaiyeoba, 2002; Yakubu and Mashi, 2016; Oyedele *et al.*, 2014) and such changes have direct effects on soil productivity. The changes in soil productivity could be positive due to drainage, tillage and addition of lime and fertilizer or negative due to soil erosion, loss of organic matter, physical structure and other degrading processes (Mallo, 2010).

In most natural environments such as soil, soil properties within a site on the landscape are relatively similar. It is noted that spatial characterization of soil properties is necessary in order to locate homogenous areas to be carefully managed for agricultural sustainable development (Jafar *et al.*, 2008).

Land use change, if not based on proper scientific investigation affects many soil properties and leading to increased destruction and erosion. The result of the negative changes in soil is deterioration of soil fertility depletion, forming a vicious cycle that is difficult to break. Good knowledge of soil properties in any given environment is a necessary for redressing negative trend and to ensure both food security and environmental sustainability. Thus, the aim of the study is to determination of physical and chemical properties of upland soils for agriculture in the Southern Guinea Savanna Zone of Nigeria becomes imperative to suggest appropriate measures that have the potential to remediate the soil.

MATERIALS AND METHODS

Study Areas

The experiment was carried out in four different locations in the Southern Guinea Savanna zone of Nigeria. The locations include Abuja (Latitude 9.0764785'N and longitude: 7.398574'E), Minna (Latitude 9.5035546'N and longitude 6.5463156'E), Lafia (Latitude 8.502676'N and longitude 8.522670'E) and Makurdi (Latitude 7°46' – 7°50'N and Longitude 8°36' – 8°40'E).

The maximum elevation of Abuja study area is 395 m above mean sea level (a.m.s.l). Minna relief is 249 m above mean sea level, Lafia relief is 205 m above mean sea level and Makurdi 97m above mean sea level. The study areas are undulating plains. The climate of the study areas is tropical savanna. The minimum temperature is 21^0C and maximum is 33.5^0C. The mean monthly temperature is 27.3^0C. The experimental areas are characterized by warm tropical climate with distinct wet and dry seasons. The wet season starts from April to October with different annual rainfall although the amount and duration vary annually.

The total annual rainfall and humidity varies about 1290 mm and 21-87% respectively in Abuja, 1204 mm and 70-83% in Minna, 1645 mm and 80% in Lafia, and Makurdi varies between 900 and 1250mm with humidity of 70-85%. The rainfall depends on the movement of the Intertropical Convergence Zone (ITCZ). The Intertropical Convergence Zone (ITCZ) is the boundary between the moisture, laden maritime wind and dry North-East wind (harmattan). The vegetation in the study areas is Guinea Savannah type, characterized by grasses with few scattered shrubs and trees.

The land in the study areas is used for cultivation of crops such as yam, cassava, guinea corn, maize, millet, groundnut, soybean, benniseed, rice, melon, and other vegetable crops. Trees crops such as mango, palm trees, citrus, cashew and other economic trees are also found in the areas.

All observations across the locations were done with a hand-held GPS. Available roads and footpaths were used as traverses. The rock outcrops were observed and described megascopically. The study areas are underlain by the rock units of the undifferentiated basement complex. The following rocks units were also observed; magnetite, igneous rock and complex basement in Abuja. Complex basement and metamorphic rock are found in Minna, granite, igneous and basement complex rocks in Lafia, whereas sandstone and alluvium are dominant in Makurdi. Map of the study locations are presented in Figure 1.

Soil Sampling

Random sampling technique was used to collect soil samples in each location. A total of nine composite auger samples were collected at three depths, viz: 0 – 15 cm, 15 – 30 cm and 30 – 45 cm (thirty six soil samples in four locations). Three (3) samples collected from each plot were bulked, air-dried and ground to pass through a 2 mm sieve before taken for analysis at the NICANSOL laboratory of the University of Agriculture, Makurdi. Undisturbed core samples were also taken and used to determine dry bulk density, total porosity and hydraulic conductivity.

Laboratory Analyses

The relative proportion of the soil separates was determined by hydrometer method of Bouyoucos (1951) (Udo *et al*., 2009). Bulk density (BD) was obtained by core method (Obi, 2000). Total porosity (TP) was obtained from bulk density value and assumed particle density of 2.65 Mg m^{-3} as (TP) = [1- Pb/Pp] x 100. Saturated hydraulic conductivity (k) was determined using darcy's equation (Obi, 2000) The glass electrode method was used to determine the soil pH (Udo *et al*., 2009). Organic carbon (OC) content of the soil samples were determined by the chromic acid oxidation procedure of Walkley – Black (Udo *et al.*, 2009). Electrical conductivities (EC) of the soil samples were measured with electric conductivity meter in a paste of 1:5 soil/water (Udo *et al*., 2009). Cation exchange capacity (CEC) of the soils was determined by Summation (TEB + EA) method (Udo *et al*., 2009). Extractable bases were determined using the ammonium acetate extract. Potassium was determined using the flame photometer. Calcium and magnesium were determined using atomic absorption spectrophotometer (AAS) (Udo *et al*., 2009). Total nitrogen was determined using the standard Macro-Kjeldahl method (Udo *et al*., 2009). Bray – I method was used to determine the available phosphorus. The base saturation (BS) value of the soils was calculated in percentages using the formular; BS = Total Exchangeable bases / CEC X 100.

The chemical properties of the soils were compared with USDA soil degradation standards (USDA, 2001 and discussed under fertility related parameters.

RESULTS AND DISCUSSION

Soil Physical Properties of the Study Sites

The physical properties of the soil of the study sites are presented in Tables 1, 2, 3 and 4 for Abuja, Minna, Lafia and Makurdi respectively. The particle size distribution of the soil indicates sandy loam texture at all the depths and locations. Sand is the dominant fine earth fraction follow by silt and clay. In general, the texture of soils showed an irregular decreasing trend with sandy loam > sandy silt loam >sandy clay. The soil exhibited an irregular trend in particle size distribution with high proportion of sand which could be attributed to the high rainfall and variation in weathering of parent material. This agrees with reports by Dasog and Patil (2011), and Amara and Momoh (2014).

Permeability of the soils of the study sites decreased with increase in soil depths in all locations. The soils of the study areas have high permeability rates varying from 5.14 to 6.82 cm/hr. This means that the soils of the study sites would transmit water at a rate of about 74 to 98 m/day. The decreased in the permeability of the soils could be attributed the high silt and clay contents at deeper depths.

The porosity of the soils increased with increase in soil depth in Abuja, Minna and Lafia due to high silt and clay contents in the subsurface horizon. Makurdi site decreased with increase in soil depths as a result of high sand and silt proportions. The total porosity ranged from 30.5 – 45 %. Conversely, soil bulk density decreased with increase in soil depth in Minna and Lafia while Abuja and Makurdi increased with increase in soil depth. The bulk density ranged from 1.32 – 1.62 Mg/cm^3. The bulk density and total pore space values of the soil were rated as moderate and were considered to favour good aeration, root penetration and free water movement in the soil. This results are in agreement with those of Donahue *et al*., 1990; Landon, 1991; Maniyunda and Malgwi, 2011 who suggested that plants perform best in bulk densities within 1.4 Mg/m^3 and 1.6 Mg/m^3 for clay and sandy soils respectively, and higher bulk density above 1.6 Mg/m^3 tends to inhibit root growth. This is due to soil's resistance to root penetration, poor aeration, slow movement of nutrients and water and build up of toxic gases and root exudates as explained by Obi (2000) and Agber *et al*. (2017). However, with continuous cultivation without proper management practices, the agricultural land use may exert some influence on bulk density and total pore spaces of the soils.

Hydraulic conductivity of the soils decreased with increase in soil depths in Abuja, Minna and Lafia as a result of high contents of silt and clay, while that of Makurdi increased with increase in soil depths due to the porous nature of soils in Makurdi formed from sandstone. Hydraulic conductivity of the soils were high (0.82 – 0.95 cm/hr) which indicate that the soil has high rate of water infiltration as the flow of water into the porous medium was as high as 0.95 cm/hr. The soil with these kinds of characteristics may be drought prone as pointed out by Agber *et al*. (2017).Water holding capacity (WHC) of the soils of study sites was low (18.63 – 32.8 %) and increased with increase in soil depth due to high infiltration rate. This might be caused by dominant sand and silt fractions of the soils indicating that the soil may be drought prone.

Soil Chemical Properties of the Study Sites

The chemical properties of the study sites are presented in Tables 5, 6, 7 and 8 for Abuja, Minna, Lafia and Makurdi respectively. The pH of the soils of the study sites was slightly acidic to moderately acidic (4.12 – 6.5) and the values decreased with increase in soil depths. The acidic nature of the soils might be attributed to the acid igneous and metamorphic rocks parent material, their well-drained condition due to high sand fractions and high rainfall which could leach out basic cations from the soil solum. The results corroborated with the findings of Akpan *et al*. (2012).The subsurface soils showed lower pH than surface soils. This could be due to leaching out of large amount of bases from the solum as a result of high proportion of macro pores, leaving behind iron and aluminium oxides. According to Patil and Dasog (1999), decreasing content of exchangeable bases and their complete downward leaching might lead to decreasing pH with depth. In addition, the low pH observed is likely to cause acid potent cations in the long run due to the high rainfall prevailing in the study area and this might encourage leaching of base forming cations from the surface and their accumulation in lower layers. However, the moderate acidity implied that nutrients are likely to be available for crop uptake. According to Odunze *et al*. (2006), pH range of 5.5- 6.5 is optimum for the release of plant nutrients.

The organic matter content of the soils was moderate at the surface and low in the subsurface soils. The content of the organic matter ranged from 5.92 – 0.51 %. According to the guidelines for rating soil fertility indicators suggested by Esu (1991), the soils of the study area could be categorized as having moderate to low amount of organic matter content. As expected, the organic matter content was observed to decrease with increasing depth. The surface soils contained high organic matter than subsurface soils. The high amount of organic matter could be attributed to the high amount of litter and crop residues at the surface layers and rapid rate of organic matter mineralization. This agrees with the findings of Amara and Momoh (2014).

The CEC of the soils of the study sites was low in Abuja (12.03 – 11.68 meq/100g), moderate in Minna and Lafia and the values ranged from 13.77 – 21.21 meq/100g and 18.13 – 14.78 meq/100g, respectively while Makurdi was shown low to moderate in CEC with values range from 7.2 – 14.1 meq/100g.The CEC value of less than 12 Cmol/kg in soil is considered minimum value of fertile soil (Maniyunda and Malgwi, 2011). Moderate CEC of the soil implies that with continuous cultivation (rainfed agriculture) without proper management practices, the soil may undergo rapid physical and chemical degradation.

Soils of the study sites showed high soil nitrogen and ranged from 0.33 – 0.83 %. The nitrogen content of the soils decreased with increase in soil depth in Abuja and Minna while Lafia and Makurdi increase with increased in soil depth as a result of leaching processes. The surface soils contained higher nitrogen levels than subsurface soils in Abuja and Minna. This high nitrogen content in surface soils could be attributed to the high organic matter content. The study revealed that the total nitrogen content of the soils could be categorized high to very high according to the guidelines suggested by FAO (2006). In field crops especially cereals, nitrogen is a very important nutrient of high demand because these crops are by nature incapable of fixing the free atmospheric nitrogen (Amara and Momoh, 2014).

The available phosphorus was low and decreased with increase in soil depth. According to the guidelines for rating soil fertility indicators suggested by FAO (2006), the soils of the study area could be categorized as having low amount of phosphorus. The most limiting nutrient in tropical soils can be regarded as soil nitrogen followed by phosphorus and the soils of Nigeria are known to be deficient in available phosphorus (Agbede, 2009). However, the present study has revealed that there is a need for soil scientists to review the phosphorus status of soils of Nigeria in order to ascertain whether the widely held notion of low phosphorus in soils of Nigeria is still holding or not.

The exchangeable bases of soils were in the order of K^+>Ca^{2+}> Mg^{2+} on the exchange complex. The exchangeable bases of the soils were as follows: K ranged from 750.07 – 0.19 mg/kg. Ca indicated nil from 0 – 30 cm soil depth due to high leaching and 93.35mg/kg was found in 30 – 45 cm depth for Abuja site, 32.99 mg/kg at 0 – 15 cm soil depth and nil from 15 – 45 cm soil depth for Minna, 2.9 – 1.9 mg/kg for Lafia and Makurdi. Mg ranged from 55.62 – 56.25 mg/kg for Abuja, 15.2 – 21.93 mg/kg for Minna, 2.6 – 2.4 mg/kg for Lafia and 2.6 – 2.4 mg/kg for Makurdi. The trend showed that the exchange complex was mostly saturated with K^+ followed by Ca^{2+} and Mg^{2+}. This order of abundance contradicted Amara and Momoh (2014) who viewed that the leaching causes preferential losses of Na^+ and K^+ in the order of Ca^{2+}> Mg^{2+}> Na^+> K^+ on the exchange complex.. The higher values of exchangeable Ca/Mg ratio indicated a decrease in extractable magnesium content in the soils. From the distribution of Ca^{2+} and Mg^{2+}, it was evident that Ca^{2+} showed the strongest relationship with all the species. Mg^{2+} was present in low amount than Ca^{2+}. This could be attributed to its higher mobility. The low values of exchangeable divalent compared to monovalent might be due to the preferential leaching of divalents compared to monovalent. According to the guidelines for rating soil fertility indicators, the soils of the study area could be categorized as having low to very high content of exchangeable K^+, very high to low content of exchangeable Ca^{2+} and Mg^{2+}.

Micronutrients of the soils were high and the trend was in the order of Mn> Cu > Zn. The results showed decreased in content at the surface as a result of leaching of appreciable amount of the micronutrients down the depths

The base saturation of the soils of the study sites were low and ranged from 10.21 – 25.4 %. The base saturation was low in both surface and subsurface soils according to the guidelines for rating soil fertility indicators suggested by FAO (2006). This is an indication that the potential availability of basic elements in the soils of the study areas may be affected.

CONCLUSION

The study revealed that the study sites were slightly acidic, low to moderate macronutrients and high micronutrients with sandy loam texture. The texture of soils showed an irregular decreasing trend with sandy loam > sandy silt loam >sandy clay. The soil nutrients indicated varied changes in contents with respect to soil depths. The values of permeability, bulk density, hydraulic conductivity, soil pH, organic matter, CEC, N, P and exchangeable bases decreased with increase in soil depth while porosity and water holding capacity of the soils increased with increase in soil depths.

Table 1: Physical Properties of Soils of Abuja

Soil Depth (cm)	Permeability (cm/hr)	Sand (%)	Silt (%)	Clay (%)	Porosity (%)	Hydraulic Conductivity (cm/hr)	Bulk Density Mg/cm^3	WHC (%)
0-15$_1$	6.12	48.19	37.45	14.36	30.6	0.84	1.39	18.6
0-15$_2$	5.13	50.44	40.12	9.44	31.5	0.75	1.28	17.7
0-15$_3$	7.11	48.21	35.90	15.89	29.4	0.96	1.50	19.6
Mean	6.12	48.84	37.82	13.23	30.5	0.85	1.39	18.63
15-30$_1$	5.16	49.02	35.17	15.81	37.4	0.75	1.54	23.5
15-30$_2$	4.17	49.97	35.23	14.80	38.3	0.84	1.41	22.4
15-30$_3$	6.15	42.75	28.29	29.37	36.5	0.66	1.41	24.6
Mean	5.16	47.25	32.89	19.99	37.4	0.75	1.45	23.5
30-45$_1$	5.43	51.0	32.0	17-0	41.0	0.78	1.50	39.8
30-45$_2$	5.34	49.23	16.63	34.14	40.0	0.67	1.48	28.7
30-345$_3$	5.55	42.75	22.12	35.13	39.9	0.89	1.34	30.9
Mean	5.44	47.66	23.58	28.76	40.3	0.78	1.44	29.8

Table 2: Physical Properties of Soils of Minna

Soil Depth (cm)	Permeability (cm/hr)	Sand (%)	Silt (%)	Clay (%)	Porosity (%)	Hydraulic conductivity (cm/hr)	Bulk Density (Mg/cm^3)	WH.C (%)
0-15$_1$	7.14	48.32	24.45	27.23	34.6	0.89	1.60	21.6
0-15$_2$	7.16	35.67	43.12	21.21	35.7	0.79	1.59	20.7
0-15$_3$	6.14	35.00	46.00	19.0	33.3	0.99	1.67	22.6
Mean	6.81	39.66	39.66	22.48	34.5	0.89	1.62	21.6
15-30$_1$	6.12	48.88	24.55	26.57	40.3	0.79	1.54	26.5
15-30$_2$	5.88	38.00	42.00	20.00	40.6	0.88	1.60	25.4
15-30$_3$	6.14	36.36	36.89	26.75	40.8	0.70	1.59	27.6
Mean	6.04	41.08	34.48	24.44	40.6	0.79	1.58	26.5
30-45$_1$	5.14	49.77	24.56	25.67	44.0	0.82	1.58	32.8
30-45$_2$	5.16	37.56	39.42	23.02	44.2	0.71	1.53	31.7
30-45$_3$	5.12	37.11	34.21	28.68	41.9	0.93	1.45	33.9
Mean	5.14	41.48	32.73	25.79	43.4	0.82	1.52	32.8

Table 3: Physical Properties of Soils of Lafia

Soil Depth (cm)	Permeability (cm/hr)	Sand (%)	Silt (%)	Clay (%)	Porosity (%)	Hydraulic conductivity (cm/hr)	Bulk Density (Mg/cm^3)	WHC (%)
0-15$_1$	6.13	50.23	27.31	22.46	32.6	0.86	1.51	20.6
0-15$_2$	7.12	50.23	30.45	19.32	33.5	0.77	1.46	19.6
0-15$_3$	6.14	19.49	45.39	35.12	31.4	0.98	1.49	21.6
Mean	6.46	39.98	34.38	25.63	32.5	0.87	1.49	20.6
15-30$_1$	6.11	60.21	21.19	18.60	39.4	0.77	1.39	25.5
15-30$_2$	5.16	57.23	29.45	13.32	40.3	0.86	1.27	24.4
15-30$_3$	5.11	51.21	32.33	16.46	38.5	0.68	1.30	26.6
Mean	5.46	56.22	27.66	16.13	39.4	0.77	1.32	25.5
30-45$_1$	5.11	58.23	23.14	18.56	43.0	0.80	1.32	31.8
30-45$_2$	5.43	59.77	20.15	20.08	43.0	0.69	1.43	30.7
30-45$_3$	5.42	52.11	33.17	14.72	41.9	0.91	1.20	32.9
Mean	5.32	56.70	25.49	17.79	42.6	0.80	1.32	31.8

Table 4: Physical Properties of Soils of Makurdi

Soil Depth (cm)	Permeability (cm/hr)	Sand (%)	Silt (%)	Clay (%)	Porosity (%)	Hydraulic conductivity (cm/hr)	Bulk Density (Mg/cm^3)	WHC (%)
0-15$_1$	7.02	75.9	13.1	11.1	46	0.85	1.44	28.0
0-15$_2$	6.14	76.7	12.8	10.5	44	0.80	1.48	17.2
0-15$_3$	7.29	70.9	15.8	13.3	45	0.89	1.45	18.5
Mean	6.82	74.5	13.9	11.6	45	0.85	1.46	21.23
15-30$_1$	6.0l	72.4	16.1	11.5	42	0.91	1.53	20.3
15-30$_2$	4.32	70.3	16.9	12.8	43	0.94	1.50	19.1
15-30$_3$	5.16	65.5	20.5	16.2	44	0.97	1.48	19.5
Mean	5.16	69.4	17.8	13.5	43	0.94	1.50	19.63
30-45$_1$	5.39	68.0	18.0	14.0	42	0.99	1.55	20.4
30-45$_2$	5.29	66.1	19.3	14.6	45	0.87	1.52	20.3
30-45$_3$	5.54	60.1	23.9	17.0	41	0.98	1.56	24.1
Mean	5.40	64.73	20.4	15.2	43	0.95	1.54	21.6

Table 5: Chemical Properties of Soils of Abuja

Soil Depth(cm)	pH (H_2O)	OM (%)	CEC Meq/100g	N (%)	P (%)	K	Ca	Mg	Mn	Cu	Zn	BS %
						←			mg/kg		→	
$0\text{-}15_1$	4.80	5.00	16.24	0.35	0.98	726.32	NIL	54.06	307.73	12.21	NIL	14.32
$0\text{-}15_2$	5.05	5.93	10.95	0.21	1.32	752.93	NIL	53.58	320.23	14.39	NIL	8.67
$0\text{-}15_3$	4.77	6.00	8.89	0.56	0.78	770.93	NIL	59.22	366.60	19.56	NIL	7.65
Mean	4.87	5.64	12.03	0.37	1.03	750.07	NIL	55.62	331.52	15.39	NIL	10.21
$15\text{-}30_1$	4.67	3.31	14.48	0.21	0.34	704.56	NIL	54.12	312.16	9.72	NIL	12.34
$15\text{-}30_2$	4.88	4.46	10.08	0.21	1.11	755.05	NIL	59.17	341.31	16.66	NIL	8.05
$15\text{-}30_2$	5.06	4.21	2.44	0.28	0.66	821.72	NIL	58.16	366.62	24.52	NIL	1.03
MEAN	4.87	3.99	9.00	0.23	0.70	760.44	NIL	57.15	340.03	16.97	NIL	7.14
$30\text{-}45_1$	4.61	1.50	14.60	0.14	0.11	716.70	NIL	52.42	306.11	9.89	NI	12.40
$30\text{-}45_2$	4.60	3.92	12.04	0.28	0.95	768.12	280.09	59.11	337.78	15.64	280.09	10.21
$30\text{-}45_3$	5.06	2.44	8.39	0.20	0.53	783.71	NIL	57.22	390.27	29.51	NIL	6.88
Mean	4.76	2.62	11.68	0.21	0.53	756.18	93.35	56.25	344.73	18.35	93.35	9.83

Table 6: Chemical Properties of Soils of Minna

Soil Depth (cm)	pH (H_2O)	OM (%)	CEC Meq/100g	N (%)	P (%)	K	Ca	Mg	Mn	Cu	Zn	BS (%)
						←		mg/kg			→	
$0\text{-}15_1$	4.50	2.94	16.95	1.12	3.12	273.29	98.98	29.75	234.45	NIL	98.98	13.61
$0\text{-}15_2$	4.37	7.82	14.57	0.89	1.45	183.07	NIL	NIL	176.27	0.11	NIL	12.57
$0\text{-}15_3$	4.60	7.00	9.80	0.49	0.79	234.98	NIL	15.85	220.64	0.75	NIL	7.40
Mean	4.49	5.92	13.77	0.83	1.79	230.45	32.99	15.2	210.45	0.29	32.99	11.19
$15\text{-}30_1$	5.59	1.92	15.27	1.10	3.10	217.03	NIL	NIL	155.12	NIL	NIL	12.54
$15\text{-}30_2$	3.83	4.83	19.20	0.42	1.32	263.29	NIL	12.35	177.17	NIL	NIL	17.09
$15\text{-}30_3$	4.11	5.49	18.48	0.32	0.58	237.73	NIL	12.37	162.31	NIL	NIL	15.67
Mean	4.51	4.08	17.65	0.61	1.67	239.35	NIL	8.24	164.87	NIL	NIL	15.10
30-451	4.20	0.99	23.95	1.11	3.02	160.65	NIL	NIL	144.53	NIL	NIL	20.76
30-452	4.65	2.84	21.25	0.70	1.21	304.74	NIL	28.24	421.97	2.99	NIL	18.45
30-453	4.18	2.44	18.42	0.28	0.44	442.37	NIL	37.54	300.19	1.90	NIL	15.42
Mean	4.34	2.09	21.21	0.70	1.56	302.59	NIL	21.93	288.90	1.63	NIL	18.21

Table 7: Chemical Properties of Soils of Lafia

Soil Depth (cm)	pH (H_2O)	OM (%)	CEC (Meq/100g)	N (%)	P (%)	K	Ca	Mg	Mn	Cu	Zn	BS (%)
						←			Mg/kg		→	
$0\text{-}15_1$	4.9	4.31	20.24	0.38	1.9	0.26	3.1	2.7	311.01	11.31	NIL	21.42
$0\text{-}15_2$	5.2	4.35	18.41	0.35	1.7	0.22	2.7	2.4	319.20	14.39	NIL	25.72
$0\text{-}15_3$	5.3	4.37	15.53	0.25	1.4	0.28	3.0	2.8	330.28	18.71	NIL	20.0
Mean	5.07	4.35	18.13	0.33	1.60	0.25	2.9	2.6	320.16	14.80	NIL	22.38
$15\text{-}30_1$	4.4	2.70	15.56	0.15	1.5	0.23	2.6	1.6	318.21	14.73	NIL	25.0
$15\text{-}30_2$	4.6	2.67	13.25	0.29	1.3	0.17	2.0	1.8	332.61	9.75	NIL	20.5
$15\text{-}30_3$	4.3	2.59	11.12	0.17	1.2	0.22	2.2	1.6	360.63	21.51	NIL	19.9
Mean	4.47	2.67	13.76	0.20	1.32	0.21	2.3	1.67	337.15	15.33	NIL	21.73
$30\text{-}45_1$	4,5	0.33	13.8	0.08	1.3	0.19	1.9	2.8	328.41	9.83	NIL	29.3
$30\text{-}45_2$	4.7	0.36	12.1	0.16	1.2	0.14	1.8	2.1	341.32	16.43	NIL	20.0
$30\text{-}45_3$	4.2	0.88	9.23	0.89	1.2	0.23	2.0	2.4	382.27	27.31	NIL	26.9
Mean	4.12	1.24	14.78	0.54	1.19	0.19	1.9	2.4	350.67	17.86	78.3	25.4

Table 8: Chemical Properties of Soils of Makurdi

Soil Depth (cm)	pH (H_2O)	OM (%)	CEC (Meq/100g)	N (%)	P (%)	K	Ca	Mg	Mn	Cu	Zn	BS (%)
						←			Mg/kg		→	
$0\text{-}15_1$	6.6	1.58	7.4	0.38	4.5	0.26	3.1	2.7	311.01	11.31	NIL	21.42
$0\text{-}15_2$	6.5	1.79	6.7	0.35	6.0	0.22	2.7	2.4	319.20	14.39	NIL	25.72
$0\text{-}15_3$	6.5	1.84	7.4	0.25	3.5	0.28	3.0	2.8	330.28	18.71	NIL	20.0
Mean	6.5	1.74	7.2	0.33	4.7	0.25	2.9	2.6	320.16	14.80	NIL	22.38
$15\text{-}30_1$	6.2	0.95	8.2	0.15	3.6	0.23	2.6	1.6	318.21	14.73	NIL	25.0
$15\text{-}30_2$	6.5	0.91	9.5	0.29	5.1	0.17	2.0	1.8	332.61	9.75	NIL	20.5
$15\text{-}30_3$	6.2	0.83	10.9	0.17	3.0	0.22	2.2	1.6	360.63	21.51	NIL	19.9
Mean	6.3	0.89	9.5	0.20	3.9	0.21	2.3	1.67	337.15	15.33	NIL	21.73
$30\text{-}45_1$	5.9	0.33	13.8	0.08	3.4	0.19	1.9	2.8	328.41	9.83	240.01	29.3
$30\text{-}45_2$	6.3	0.36	12.1	0.16	4.0	0.14	1.8	2.1	341.32	16.43	NIL	20.0
$30\text{-}45_3$	6.2	0.88	16.4	0.89	2.9	0.23	2.0	2.4	382.27	27.31	NIL	26.9
Mean	6.1	0.51	14.1	0.54	3.4	0.19	1.9	2.4	350.67	17.86	80.00	25.4

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