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Relationships and Prediction of Organic Matter from Selected Soil Properties in the Nigerian Environment

Ayodele Owonubi

Forestry Research Institute of Nigeria; Federal College of Forestry, Jos; Department of Horticulture and Landscape Technology, Jos, Plateau State, Nigeria; Email: ayowonubi@gmail.com,

Abstract

In tropical soils, particularly those found in Nigeria, soil organic matter is an essential component. This is due to its function in fertility, production, and soil conservation. The objectives of this study were to: (1) access the relationship between organic matter and selected soil properties within the scope of the Nigerian environment; and (2) evaluate the role of this relationships in the prediction of organic matter levels. Primary soil data was obtained from 32 profiles dug in the Nigerian guinea savanna area. Secondary data involving 1,176 soil profiles and 3, 299 soil samples across the ecological zones in the Nigerian environment were obtained from the African Soil Profiles Data Base (version 1.2). Correlation analysis indicated that the selected soil properties had weak or no linear relationship with organic matter. However, average soil depth had a highly significant ($p<0.01$) slightly weak negative linear relationship ($r = -0.4$) with organic matter. On the other hand, organic matter had a highly significant strong positive linear relationship ($r = 0.8$) with total nitrogen. Regression equations were also examined, and the article's validation results show that using organic matter data to forecast the total nitrogen levels in Nigerian soils has a lot of potential. It is therefore recommended that more elaborate validation studies be done to fully under the relationships between organic matter and nitrogen in Nigerian soils.

Key words: Organic matter, Nigeria, Soil properties, Nitrogen, NDVI

Introduction: One of the most vital components of Nigerian soils, particularly in the tropical setting, is soil organic matter. According to Brady and Weil (1999), organic matter enhances soil tilth, decreases compaction and surface crusting, acts as a store of plant nutrients and water, and is crucial for the formation and stability of soil structure. This underscores the importance of organic matter on soil productivity, fertility, and conservation. Consequently, the proper management of soil organic matter is, therefore, important to food security and the protection of marginal lands (Martius, Tiessen, and Vlek, 2001). Furthermore, it was noted that appropriate management of soil organic matter in the tropics, still requires considerable research into the regional variability of soil organic matter quantity, quality and function; the importance of the quality of input material; the role of below-ground versus mulched organic matter; the role of recalcitrant materials such as biochar in building a stable soil organic matter fraction in the long-term; and how to balance the need for stable forms against the need for short-term nutrient availability. Reports by Conteh and Kamara (2020) indicates that under tropical climatical conditions, soil organic matter vary with vegetation (higher in forest than in savanna soils), climate (higher in mountain forests that in lowland forests), soil texture (increasing with increasing clay and silt content), minerology (higher in volcanic soils due to stabilizing effect of allophane on organic matter) and land use (higher in undisturbed soil than those under continuous cultivation). It was also noted that results of various studies indicate that a significant fraction of soil organic matter within soil aggregates and that associated with clay minerals is physically protected from decomposition. Much of this organic carbon is thought to comprise a pool with intermediate residence time (for example: 10 - 50 years), but which may decompose much faster upon soil disturbance. Within the context of the Nigerian environment, more information is needed to fully understand organic matter distribution and relationships with soil characteristics and factors in the various ecosystems. Therefore, the objective of this study was to access the relationship between organic matter and selected soil properties within the scope of the Nigerian environment.

Materials and Methods: Field and Laboratory Studies: Primary soil data used for validation studies were obtained from 32 soil profiles dug at random within the Nigerian guinea savanna. Soil samples were obtained from genetic horizons using guideline described in the soil survey manual (Soil Survey Division Staff, 1993). Soil samples were subject to laboratory analysis: Particle size analysis was carried out using the hydrometer method as described by Hossain, Islam, Badhon, and Imtiaz, (2021). Organic carbon was determined by the Walkley-Black dichromate wet oxidation method as documented by FAO (2021a). The Kjeldahl method was used for determination of total nitrogen (FAO, 2021b).

Data Analysis: Correlation and regression analysis were performed on secondary soil data obtained from the African soil data base (version 1.2) as documented by Leenaars, Oostrum, and Gonzalez (2014). 1200 data points were identified retrieved from the database. One way analysis of variance was used to compare data predicted from regression equations and primary soil data obtained by laboratory analysis. Descriptive statistics were also performed on secondary soil data. Geographic information Systems was used to display vegetation, and secondary soil data points obtained from Fick and Hijmans (2017), and Leenaars et al (2014) respectively. Normalized Difference Vegetation Index (NDVI) for Nigeria at a resolution of 250m for the month of January 2001 was obtained from the International Research Institute for Climate and Society (IRI), Moderate Resolution Imaging Spectroradiometer (MODIS) analysis tool. NDVI data for the year 2001 was used because most of the secondary soil data used for this study were obtained around that period.

Results and Discussion: **Relationships between Soil Characteristics and organic matter**: Figure 1 shows distribution of soil sample points obtained from the African soil data base and variation in vegetation characteristics across the Nigerian landscape. Vegetation characteristics is largely a function of climate and soil types and as such gives an overview of the gross variation in ecosystem characteristics within the Nigerian environment. Healthy vegetation growth, such as forests, will yield high NDVI values closer to one, while low vegetation will yield values close to 0.2 (Menesses – Tovar; 2011). Vegetation is the major source through which soil acquires its organic matter content.; Table I shows general soil characteristics across the Nigerian landscape. Extremely high variation was observed among soil properties. Coefficient of variation was highest for soil organic carbon (117.49). These high variation in soil organic carbon could be due to effects of the variable nature (across the Nigerian environment) of factors such as climate, vegetation land use, soil texture, depth, and minerology as was noted by Conteh and Kamara (2020). The relationship among these soil properties is presented in Table 2. In most cases no strong relationships were observed between soil organic carbon and soil properties and could also be due to factors earlier mentioned. However. there was a highly significant ($p < 0.01$) moderate negative correlation between soil organic carbon and average soil depth ($r = -0.404$). This is not unexpected as has been observed in various soil studies within the Nigerian environment. For example, in studies carried out by Ande, (2010), Eshett et al, (1990) and Aki et al, (2014); organic matter was observed to decrease with increasing soil depth. Also, a highly significant strong positive relationship was observed between soil organic carbon and total nitrogen ($r = 0.805$). This indicates that nitrogen contents in Nigerian soils are mainly in the organic form. Relationships between soil organic matter and total nitrogen has been the subject of various soil studies. For example, Brady and Weil (1999) proposed various relationships between soil organic carbon and total nitrogen which could be expressed mathematically as follows (equation 1 and 2):

$$TN = \frac{OM}{1.72} \times \frac{1}{12} \quad \text{…...…….. equation 1}$$

$$TN = \frac{OM}{1.72} \times \frac{1}{20} \quad \text{…...…….. equation 2}$$

$$TN = 0.1152 + 0.072182\left(\frac{OM}{1.72}\right) \quad \text{…...…….. equation 3}$$

$$TN = 0.1707 - 0.000343\,AD - 0.1245\,GMWD + 0.07075\left(\frac{OM}{1.72}\right) \quad \text{…...…….. equation 4}$$

Where:

TN = total nitrogen (%)

OM = organic matter (%)

AD = average soil depth

GMWD = geometric mean weight diameter

Equation 1 was proposed for most soil types (excluding soils of arid areas) whereas equation 2 was proposed for Histosols, humid and wetland soils. Furthermore, the linear regression equation between total nitrogen and organic matter (equation 3), and the multiple linear regression equation between nitrogen on one hand and organic matter, average soil depth and soil particle size distribution expressed as geometric mean weight diameter (equation 4) was highly significant however only 65% of the variation in the distribution of total nitrogen can be accounted for by the equations.

Model Validation: The mathematical models (equation 1 – 4) were tested with an independent data set obtained from 32 soil profiles in selected areas of the Nigerian guinea savanna (Table 3) as a validation procedure to test whether models developed from the African soil data base and that obtained from Brady and Weil (1999) were not merely artifacts of the data. Soil data presented in Table 3 ranged from Entisols to Inceptisols; with particle size distribution having a geometric mean weight diameter ranging from 0.21 to 0.87. Mean organic matter content in soil was1.44% with a standard deviation of 0.84 and a coefficient of variation of 58.32. On the other hand, mean total nitrogen contents was

0.042% with a standard deviation of 0.024 and a coefficient of variation of 56.42.

Variation in the distribution of total nitrogen and organic matter is much lower compared to that obtained from the African soil database most likely due to reduced variability in ecological conditions within the Nigerian guinea savanna. This was underscored by Foth (1990), who documented wide variations in soil organic matter distributions between forest and grassland ecosystems. Summary statistics of soil nitrogen predicted by equations 1 to 4 is presented in Table 4. There was highly significant difference ($P < 0.01$) between soil nitrogen predicted by the equations and that observed in the laboratory. Further analysis using Fisher pairwise comparison indicated that means were in the order: Equation 4 > Equation 3 > Equation 1 > Equation 2 = Observed. Hence soil nitrogen contents obtained from laboratory analysis and that predicted by equation 2 were statistically similar ($P < 0.05$). The significant difference between soil nitrogen levels predicted by equations 3 to 4 and that observed from laboratory analysis could be due to great variation in ecological conditions, geology, land use, and consequently soil types across the Nigerian landscape. These factors have been noted by Foth, (1990) and Conteh and Kamara (2020).

Conclusion: The relationships between organic matter and selected soil properties were investigated across the Nigerian environment. Weak relationships were observed in most cases. These relationships were most likely obscured by great variation among the various ecosystems. However moderate negative correlation and strong positive correlation were observed between organic matter and average soil depth and soil nitrogen, respectively. This study further underscored the potential of mathematical models in predicting nitrogen levels from soil organic matter data. For the soils studied, equation 2 was significantly effective in predicting soil nitrogen levels. Consequently, this study has shown that the relations between soil organic matter and soil nitrogen can be explored to develop pedo-transfer functions for the prediction of soil nitrogen. However, it is recommended that for future research, similar studies should be conducted for relatively homogeneous ecosystem for more reliable outcomes.

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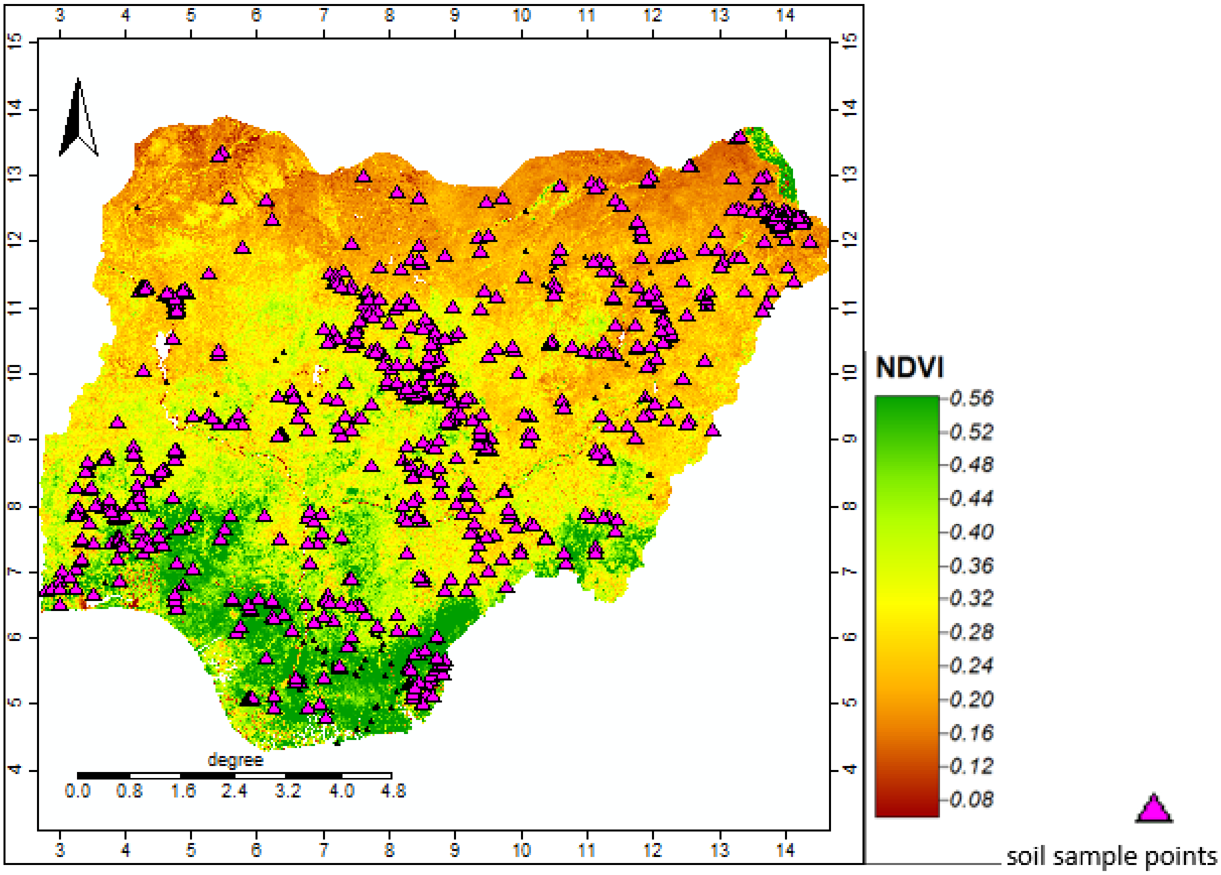

Figure 1: Distribution of soil sample points from African soil data base and vegetation characteristics within the Nigerian environment

Table 1: General soil characteristics

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Sand	58.178	24.030	41.30	0.000	100.000
Silt	16.343	12.379	75.75	0.000	89.000
Clay	25.483	18.567	72.86	0.000	88.100
ECEC	13.907	14.141	101.69	0.270	60.000
CEC Soil	11.694	11.913	101.88	0.100	87.700
B sat	62.424	30.183	48.35	0.000	100.000
Org C	6.171	7.250	117.49	0.000	111.000
Total N	0.6065	0.6958	114.72	0.0000	11.3000

StDev: standard deviation, CoefVar: coefficient of variation

Table 2: Correlation analysis

	Av depth	Sand	Silt	Clay	ECEC	CEC-Soil	B-sat	Org-C
Sand	-0.077							
	0.000							
Silt	-0.070	-0.649						
	0.000	0.000						
Clay	0.145	-0.862	0.174					
	0.000	0.000	0.000					
ECEC	-0.031	-0.727	0.365	0.708				
	0.176	0.000	0.000	0.000				
CEC Soil	-0.015	-0.635	0.266	0.646	0.931			
	0.306	0.000	0.000	0.000	0.000			
B sat	-0.024	-0.086	0.085	0.054	0.422	0.189		
	0.101	0.000	0.000	0.000	0.000	0.000		
Org C	-0.404	-0.051	0.031	0.046	0.106	0.145	-0.094	
	0.000	0.001	0.059	0.004	0.000	0.000	0.000	
Total N	-0.338	-0.136	0.074	0.126	0.065	0.185	-0.116	0.805
	0.000	0.000	0.000	0.000	0.039	0.000	0.000	0.000

Cell Contents
Pearson correlation
P-Value

Table 3: The 32 soil profiles used to test models is presented here.

N	E	Profile No.	Horizon	average depth (cm)	GMWD	N (%)	OM (%)
9.150085	9.780018	1	A	6.00	0.64	0.051	1.73
			AC	21.00	0.72	0.038	1.30
			C1	42.50	0.71	0.025	0.87
9.141644	9.774425	2	A	7.50	0.35	0.095	3.29
			C1	32.50	0.35	0.059	1.68
			C2	57.50	0.35	0.022	0.07
9.13856	9.771327	3	A	20.00	0.29	0.062	2.08
			C1	65.00	0.29	0.042	1.46
9.771327	9.812774	4	A	22.50	0.37	0.007	0.23
			BA	47.50	0.37	0.014	0.41
			B	127.50	0.37	0.005	0.18
9.085832	9.809885	5	A	22.50	0.58	0.024	0.81
			BA	55.00	0.58	0.028	0.90
			B1	80.00	0.58	0.030	0.97
			BC	102.50	0.58	0.031	1.03
			C1	160.00	0.58	0.041	1.34
9.083862	9.816099	6	A1	12.50	0.74	0.024	0.76
			A2	32.50	0.74	0.047	1.72
			B1	60.00	0.74	0.038	1.31
			B2	95.00	0.74	0.028	0.90
			C1	120.00	0.74	0.026	0.82
9.09727	9.809663	7	A	15.00	0.72	0.055	1.83
			B1	42.50	0.72	0.020	0.65
			B2	67.50	0.72	0.027	0.87
			B3	120.00	0.72	0.033	1.09
			BC	180.00	0.72	0.012	0.37
9.114471	9.786592	8	A	11.00	0.53	0.056	1.86
			B	38.50	0.53	0.018	0.59
			C1	97.50	0.53	0.059	1.96
			C2	175.00	0.53	0.041	1.32
			C3	265.00	0.53	0.023	0.68
9.160063	9.781774	9	A	22.50	0.58	0.053	1.77
			C1	21.00	0.58	0.036	1.11
			C2	21.00	0.58	0.054	1.83
9.168299	9.765158	10	A	15.00	0.74	0.046	1.52
			C1	21.00	0.74	0.030	1.03

Table 3 (continued): The 32 soil profiles used to test models is presented here.

N	E	Profile No.	Horizon	average depth (cm)	GMWD	N (%)	OM (%)
9.48714	9.12178	11	Ap	12.50	0.22	0.038	1.34
			B1	37.50	0.22	0.035	1.21
			B2	75.00	0.22	0.017	0.59
			B3	126.50	0.22	0.005	0.17
9.4861	9.12197	12	Ap	10.00	0.62	0.059	2.03
			B1	47.50	0.62	0.062	2.12
			B2	122.50	0.62	0.013	0.45
			B3	185.00	0.62	0.054	1.86
9.49915	9.11882	13	Ap	19.00	0.40	0.055	1.90
			Bc1	51.50	0.40	0.047	1.62
			Btc	76.00	0.40	0.032	1.10
			Bc	103.50	0.40	0.030	1.08
9.11882	9.14671	14	Ap	7.50	0.40	0.042	1.45
			Bc1	57.50	0.40	0.037	1.28
			Bc2	150.00	0.40	0.024	0.82
9.50693	9.11926	15	A	7.50	0.60	0.120	4.16
9.510165	9.102373	16	A	12.50	0.41	0.100	3.51
			Bc1	45.00	0.41	0.080	2.76
			Bc2	92.50	0.41	0.042	1.45
9.78431	8.97315	17	A	11.50	0.23	0.083	2.85
			AC	86.50	0.23	0.023	0.79
9.7985	8.97542	18	A	11.50	0.32	0.067	2.32
			B	46.50	0.32	0.014	0.54
			BC	110.00	0.32	0.010	0.33
9.84796	8.97508	19	A	10.00	0.31	0.083	2.85
			B1	32.50	0.31	0.066	2.28
			B2	82.50	0.31	0.029	0.99
				150.00	0.31	0.084	2.90
9.769479	8.851754	20	A	11.50	0.53	0.094	3.23
			C	31.50	0.53	0.065	2.23
9.784176	8.832954	21	A	15.00	0.29	0.058	1.99
			AB	40.00	0.29	0.032	1.12
			B	70.00	0.29	0.053	1.82
			C	120.00	0.29	0.022	0.74
9.792597	8.830599	22	A	7.50	0.53	0.073	2.52
			B1	22.50	0.53	0.008	0.29

Table 3 (continued): The 32 soil profiles used to test models is presented here.

N	E	Profile No.	Horizon	average depth (cm)	GMWD	N (%)	OM (%)
7.15805	7.50006	23	A	12.50	0.87	0.048	1.64
			BA	38.50	0.32	0.029	0.99
			B	101.00	0.24	0.011	0.37
7.1568	7.50397	24	A	7.50	0.83	0.039	1.35
			AB	32.50	0.34	0.032	1.09
			B	100.00	0.32	0.074	1.05
7.1575	7.51213	25	A	7.50	0.62	0.043	1.47
			AB	42.50	0.44	0.028	0.98
			B	110.00	0.33	0.064	2.20
7.15517	7.51097	26	A	7.50	0.58	0.018	0.62
			AB	35.00	0.80	0.079	2.73
			B	102.50	0.47	0.014	0.50
7.16709	7.51696	27	A	20.00	0.60	0.079	2.73
			AB	57.50	0.62	0.027	0.94
			B	82.00	0.49	0.025	0.87
			C	94.50	0.48	0.058	1.99
7.16442	7.51774	28	A	7.50	0.83	0.068	2.33
			AB	42.50	0.63	0.031	1.06
			B	110.00	0.63	0.060	2.08
7.16632	7.51714	29	A	12.50	0.87	0.076	2.61
			AB	40.00	0.62	0.033	1.14
			B	102.50	0.64	0.029	0.99
7.16978	7.46412	30	A	12.50	0.83	0.069	2.39
			AB	40.00	0.64	0.037	1.29
			B	102.50	0.48	0.068	2.36

Table 4: Summary statistics for validation data

Soil Nitrogen (%)	N	Mean	StDev	95% CI
Observed	104	0.04283^{d}	0.02416	(0.03638, 0.04927)
Predicted N from equation 1	104	0.06974^{c}	0.04067	(0.06329, 0.07618)
Predicted N from equation 2	104	0.04184^{d}	0.02440	(0.03540, 0.04828)
Predicted N from equation 3	104	0.17561^{b}	0.03523	(0.16916, 0.18205)
Predicted N from equation 4	104	0.18525^{a}	0.03895	(0.17881, 0.19170)

Pooled StDev = 0.0334420

Means that do not share a letter are significantly different (P≥0.05)

Note: CI=Confidence interval; StDev=standard deviation; N= number of samples