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ORIGINAL RESEARCH ARTICLE

Relationships Between pH Buffer Capacity and Selected Soil Properties of an Agrarian area in Samaru, Nigeria

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ABSTRACT
The objectives of this research were to investigate the nature of pH buffer capacity and evaluate its association selected soil characteristics the study area. Soil samples from ten profile pits from within the study area were collected from genetic horizons. Soil samples were tested in the laboratory for electrical conductivity and pH buffer capacity using standard procedures. Soil data were analyzed using descriptive statistics. One-way analysis of variance and correlation analysis were applied to determine effects and relationships of selected soil properties with soil pH buffer capacity. The selected soil properties included particle size distribution, electrical conductivity, organic matter, cation exchange capacity and soil pH. Analysis of variance indicated that there were no significant effect of soil depth or drainage condition on distribution of pH buffer capacity in the study area. Correlation analysis indicated a non-significant weak relationship between pH buffer capacity and selected soil properties of the study area. This suggest that multiple interrelated factors could be responsible for the distribution of pH buffer capacity in the study area.

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INTRODUCTION

One of the main problems with soil acidity is the relationship between the total acidity of the system and the intensity of acidity. This relationship is defined as the soil buffer capacity (Jansen van Rensburg, 2009). Buffering capacity qualifies the ability of a solution to resist changes in pH by either absorbing or desorbing H+ and OH- ions when an acid or base is added to a buffer system, the effect of pH change can be large or small, which depends on both the initial pH and the capacity of the buffer to resist change in pH. Soil buffering capacity ensure stability in soil pH and it is the ability to prevent drastic pH change in soils (Neilsen *et al*., 1997, Curtin *et al*., 1996; Weaver *et al*., 2004).

The climate of Samaru is tropical continental, with distinct seasonal patterns that range from chilly to hot, dry, and humid to wet (Iloeje, 2004). Both tropical continental and equatorial maritime air masses, which cover the entire nation, are reflected in these two seasons. The long-term mean annual rainfall is 1100 mm (monomodal), and the length of the season is about 130 to 190 days from late May to September/October (Yaro et. al., 1999).
A complex of igneous and metamorphic rocks, primarily of Jurassic to Precambrian age, underlie the entire region. These undifferentiated Basement Complex rocks are essentially granites, gneisses, migmatites, schists and quartzites that are rich in quartz and low in divalent cations (Owonubi, 2008). In addition to regional soils made of Basement Complex rocks, fine-grained loess material (deposited by Saharan winds) has also contributed to the development of soils over the Samaru region over time (Wall, 1978; Iloeje, 2004). Characteristics of the harmattan dust (Owonubi, 2017) also reveal that enrichment through annual dust depositions is a significant process in the development of the soils.

The study area is situated within the guinea savanna zone and precisely at the Institute for Agricultural Research (IAR) farm, Ahmadu Bello University, Samaru, Zaria. A surge in intensive crop production in the study area especially from the seventies has led to soil acidification and a decline in soil productivity (Owonubi, 2017). However, there is dearth of

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information with respect to soil pH buffering capacity for which to base management decisions. Therefore, the objectives of this research were to investigate the nature of pH buffer capacity and evaluate the association between the buffer capacity and selected soil characteristics the study area.

MATERIALS AND METHODS

The study area was stratified based on soil drainage classes identified by Owonubi (2017). A total of ten soil profiles were dug (Figure 1). Profile pits were dug in each soil drainage class. The identified drainage classes were well drained (profiles 1, 2, 4, 5), moderately well drained (profiles 3, 6, 7), imperfectly drained (profiles 8), and poorly drained (profiles 9, 10). Soil samples were obtained from generic horizons for laboratory analysis.

Laboratory Analysis

The soil samples were dispersed in 5% Calgon (sodium hexametaphosphate) solution by shaking on a reciprocating shaker. The hydrometer method, as described by Gee and Bauder (1986), was used to determine the particle size distribution. Soil pH was determined 0.01M $CaCl_2$ solution at a 1:2.5 soil/solution ratio as described by McLean (1982). Soil electrical conductivity was determined in 1:2 soil/solution ratio. The Single Addition $Ca(OH)_2$ method of Kissel and Sonon (2014) was used to determine pH buffer capacity.

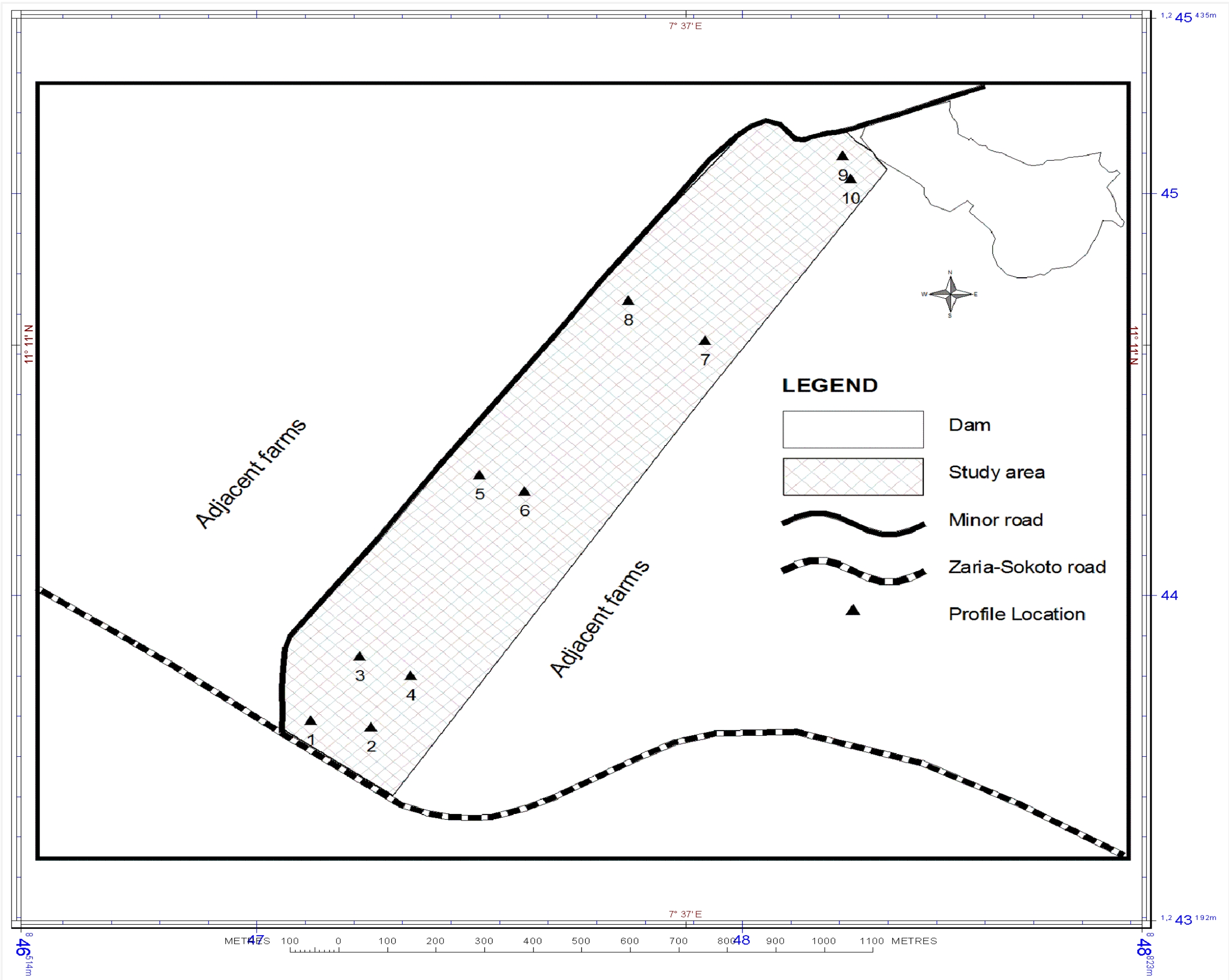

Figure 1: Map of study area (source: Owonubi, 2017)

The Walkley-Black dichromate wet oxidation method, as described by Nelson and Sommers (1982), was used to measure the amount of organic matter with concentrated sulfuric acid was used as a catalyst to activate the reaction. Cation exchange capacity at pH 7 was determined by the NH_4OAc saturation method (Rhoades, 1982).

Statistical Analysis

Descriptive statistics was used to analyze the results of soil laboratory analysis. One-way analysis of variance was used to assess effect of soil drainage class on pH buffer capacity one hand and effect of soil depth and pH buffer capacity on the other hand. Correlation analysis was conducted to assess relationship between pH buffer capacity and soil properties.

RESULTS AND DISCUSSION

pH Buffer Characteristics of the Study Area

The ability of a particular soil to resist pH changes is known as soil pH buffering capacity, and it is a crucial aspect in precisely estimating the amount of lime needed to neutralize soil acidity and bring it to the appropriate pH level (Liyanage *et al*., 2012). Distribution of pH buffer capacity values down the soil profiles studied were generally irregular and follow no trend. Descriptive statistics of pH buffer capacity for soils of the study area is presented in Table 3 and 4. These shows that mean pH buffer capacity values were 1096.6, 1132.2, 843.3, and 1014.9 (mg $CaCO_3$ (kg soil)$^{-1}$pH^{-1}) for soils in well drained, moderately well drained, imperfectly rained and poorly drained areas respectively. Furthermore, mean values for surface and subsurface soils were 1038.4 and 1076.1 (mg $CaCO_3$ (kg soil)$^{-1}$pH^{-1}) respectively. However, analysis of variance (Table 5 and 6) revealed that there were no significant differences ($p > 0.05$) in pH buffer values among soil drainage classes or between soil depth classes. According to classifications presented by Thomas *et al* (2004), the pH buffer values of the soil are generally very low to low. Similar results were obtained by Hartemink (1998) and Thomas *et al.* (2004) for some agricultural soils.

General Soil Characteristics of the study Area

In summary, the soils are generally acidic and have very low cation exchange capacities (<15 cmol/kg) and soil organic matter content. Soils have loam textures in most cases in surface soils whereas subsurface soils have clay to clay loam textures generally. Also, electrical conductivity tests were performed for the soils in this current study. Electrical conductivity values (Table 1) were very low. This is however not unlikely as the soils are acidic in nature.

Additionally, Thomas *et al.* (2004) pointed out that low pH buffer capacity values suggest that soil acidity is likely to change relatively quickly when the soil receives acid inputs, but the opposite is also typically true in that smaller amounts of lime are required to achieve a significant pH increase. Factors influencing pH buffer capacity in soils include the type and amount of clay mineral and organic matter (Brady and Weil, 1999). Yong (1990) noted the pH buffer capacities of certain clay minerals and reported that they were in the following order of magnitude: illite > smectite > kaolinite.

According to Jansen van Rensburg's 2009 research on pH ranges that affect crop production, buffering at intermediate pH values (5.0 to 7.5) is primarily accomplished through cation exchange reactions in which functional groups linked to variable-charge minerals and soil organic matter serve as H+ and OH- ion sinks. Furthermore, for some South African Soils, Jansen van Rensburg (2009) observed that extractable aluminium was the dominant factor affecting buffer capacity within the pH range of < 4.5 to 6.5, whereas within the pH range of 6.5 to 8.5, clay was the dominant factor affecting buffer capacity.

Table 1: Soil characteristics of the study site

Drainage Class	Profile	Horizon	Depth	pH	pHBC	EC	OM	CEC	Clay	silt	Sand
Well Drained	1	Ap	0-17	4.15	1211	0.006	0.35	4.7	19	29	52
		BA	17-34	4	1232	0.006	0.24	6.4	37	29	34
		Bt	34-65	4.2	1015	0.007	0.12	7.8	45	25	30
		Btc	65-95	4.7	821	0.007	0.1	5.7	31	19	50
		Btv	95-150	4.1	852	0.0091	0.07	5.5	23	15	62
Well Drained	2	Ap	0-6	4.9	1095	0.089	0.17	4.7	19	35	46
		BA	6-35	4.15	920	0.007	0.15	7	43	25	32
		Bt1	35-73	4.5	945	0.009	0.11	5.3	45	25	30
		Bt2	73-115	5	945	0.009	0.1	7.7	37	25	38

Table 1: Continued

Drainage Class	Profile	Horizon	Depth	pH	pHBC	EC	OM	CEC	Clay	silt	Sand
Moderately well drained	3	Ap	0-14	4.2	932	0.008	1.69	10.3	25	37	38
		BA	14-24	4.5	812	0.0011	0.58	7.6	31	27	42
		Bt1	24-55	3.8	2300	0.006	0.56	8.2	41	23	36
		Bt2	55-87	3.3	1278	0.007	0.38	7	45	27	28
		Bt3	87-125	4.1	1150	0.008	0.24	10.8	43	25	32
		Bt4	125-165	4.5	697	0.011	0.23	7.9	35	23	42
Well Drained	4	Ap	0-6	4.5	1380	0.001	1.51	5.7	15	29	56
		BA	6-23	4.6	841	0.001	0.65	9.4	31	27	42
		Bt1	23-52	5.5	1278	0.006	0.47	8.4	37	25	38
		Bt2	52-95	5.1	1095	0.008	0.23	6.9	41	25	34
		Bt3	95-119	5	1150	0.001	0.1	8.1	35	21	44
		Bt4	119-165	5.5	1000	0.0012	0.07	10.45	35	19	46
Well Drained	5	Ap	0-22	4.2	1380	0.001	1.41	8.6	19	39	42
		BA	22-49	4.9	1353	0.007	0.76	10.1	39	31	30
		Bt1	49-110	4.6	1015	0.007	0.5	10.7	45	25	30
		Bt2	110-140	4.6	1255	0.008	0.46	8.2	37	25	38
		Btv3	140-170	4.2	1150	0.008	0.2	7.4	37	27	36
Moderately well drained	6	Ap	0-17	4.65	1211	0.006	1.75	4.9	17	39	44
		BA	17-43	4.6	1232	0.006	0.82	8.5	37	23	40
		Bt	43-97	4.4	1015	0.007	0.67	6	39	23	38
		Btv	97-130	4.1	821	0.007	0.44	3.4	45	25	30
		Btc	130-150	4.6	852	0.0091	0.15	8.9	35	25	40
Moderately well drained	7	Ap1	0-22	5	1095	0.089	1.51	5.4	15	39	46
		Ap2	22-44	4.3	920	0.007	0.55	6.1	25	39	36
		Bt1	44-84	4.7	945	0.009	0.45	10.85	47	31	22
		Bt2	84-112	4.7	945	0.009	0.31	10.6	45	27	28
		Btv3	112-170	4.2	932	0.008	0.15	11.1	39	27	34
Imperfectly Drained	8	Ap	0-11	4.9	812	0.0011	1.7	9.2	25	45	30
		AB	11-37	4.4	2300	0.006	0.7	6.6	25	37	38
		Bt1	37-59	3.8	1278	0.007	0.49	7.2	43	29	28
		Bt2	59-92	3.8	1150	0.008	0.21	10.9	45	29	26
		Btv3	92-165	4.15	697	0.011	0.14	8.15	41	23	36
Poorly Drained	9	Ap	0-8	4.06	1380	0.001	3.3	15.4	27	27	46
		AB	8-32.5	3.7	841	0.001	1.17	4.4	17	27	56
		Bt1	32-65	3.6	1278	0.006	1.17	5.55	25	31	44
		Bt2	65-85	4.7	1095	0.008	0.39	5.8	33	19	48
		Bcg	85-152	4.3	1150	0.001	0.2	8.3	37	21	42
Poorly Drained	10	Ap	0-18	3.5	1000	0.0012	1.01	19	41	29	30
		AB	18-32	3.5	1380	0.001	0.59	12.3	37	29	34
		Bg1	32-58	3.85	1353	0.007	0.46	9.3	33	25	42
		Bg2	58-82	4.1	1015	0.007	0.35	9.9	41	13	46
		Btg1	82-126	4.35	1255	0.008	0.2	8.6	41	15	44
		Btg2	126-165	4.9	1150	0.008	0.1	8.3	41	21	38

Note: OM: organic matter (%), CEC: cation exchange capacity (cmol/kg), units of clay silt and sand in percent, pHBC: pH Buffer Capacity (mg $CaCO_3$ (kg soil)$^{-1}$pH^{-1}); EC: Electrical Conductivity (ds/m).

Relationships Between pH Buffer Capacity and Selected Soil Properties

Low levels of organic matter content and cation exchange capacity, as reported by Thomas *et al*. (2004) for viticultural soils, may be the cause of the low pH buffer capacity values found in this study. Sub soils of the study area is dominated by a kaolinitic mineralogy as inferred by Owonubi (2017). Jansen van Rensburg (2009) observed that organic matter is the dominant factor influencing pH buffer capacity in soil dominated by kaolinitic mineralogy. Correlation analysis between pH buffer capacity and selected soil properties is presented in Table 6. The outcome demonstrates that although there were no statistically significant associations ($p > 0.05$), there were some weak relationships between specific soil parameters and pH buffer capacity. In contrast, buffer capacity was shown to relate to soil characteristics like pH, texture, organic matter, and cation exchange capacity, according to Zusevics (1980). Additionally, Jansen van Rensburg (2009) demonstrated a highly substantial correlation between clay concentration, organic carbon, and extractable aluminum and pH buffer capacity throughout the pH range of 4.5 to 8.5.

Table 2: Descriptive Statistics for pH buffer Capacity (mg $CaCO_3$ (kg soil)$^{-1}$pH^{-1})

Drainage-Class	Mean	StDev	Minimum	Maximum
Well drained	1096.6	180.9	821.4	1380.0
Moderately well drained	1132.2	385.5	697.0	2300.0
Imperfectly drained	843.3	65.1	766.7	945.2
Poorly drained	1014.9	214.0	766.7	1500.0

Table 3: Descriptive statistics of pH buffer capacity (mg $CaCO_3$ (kg soil)$^{-1}$pH^{-1}) and soil depth

Depth Class	N	Mean	StDev	95% CI
Surface soil	14	1038.4	220.5	(892.8, 1183.9)
Subsurface soil	38	1076.1	286.8	(987.7, 1164.4)

Pooled StDev = 271.173

Table 4: Analysis of Variance for pH buffer capacity (mg $CaCO_3$ (kg soil)$^{-1}$pH^{-1}) versus drainage class

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Drainage-Class	3	365614	121871	1.76	0.168
Error	48	3325674	69285		
Total	51	3691289			

Table 5: Analysis of variance of pH buffer capacity (mg $CaCO_3$ (kg soil)$^{-1}$pH^{-1}) versus soil depth

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Depth-Class	1	14560	14560	0.20	0.658
Error	50	3676729	73535		
Total	51	3691289			

Table 6: Correlation Analysis between pH buffer capacity and selected soil properties

	pHBC	EC	pH	OM	CEC	Clay	silt
EC	0.050						
	0.724						
pH	-0.088	0.122					
	0.536	0.388					
OM	-0.091	-0.187	-0.116				
	0.520	0.184	0.413				
CEC	0.107	-0.159	-0.148	0.224			
	0.449	0.260	0.294	0.111			
Clay	0.161	-0.146	-0.096	-0.543	0.352		
	0.254	0.302	0.500	0.000	0.011		
silt	-0.035	0.091	-0.010	0.534	-0.035	-0.487	
	0.805	0.520	0.945	0.000	0.806	0.000	
Sand	-0.152	0.091	0.114	0.185	-0.363	-0.729	-0.242
	0.283	0.523	0.421	0.189	0.008	0.000	0.084

Cell Contents; Pearson correlation; P-Value

CONCLUSION

Soil pH, electrical conductivity, organic matter, particles size distribution and cation exchanges capacity were evaluated during the study. The one-way analysis of variance was used to analyze the soil data, whereas correlation analysis was utilized to identify the relationship between pH buffer capacity and some selected soil properties. The result showed weak relationship between the selected properties and pH buffer capacity though these were not statistically significant. Also, there were no significant effect of soil depth and drainage condition on the nature of pH buffer capacity in the study area. To safe guard against further decline in soil productivity in the study area, data obtained in this study for pH-buffer capacity could serve as a guide for future lime application for adequate control of soil acidity.

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