Correlation Studies to Evaluate the Effect of Selected Soil Physical and Chemical Properties on Phosphate Availability in Hadejia-Nguru Floodplains, Nigeria.

ABSTRACT

The purpose of the study was to evaluate the effect of selected soil physical and chemical properties on Phosphate (P) availability in Hadejia-Nguru floodplains using correlation matrix. Three different floodplains were strategically selected. Disturbed soil samples were collected at three different sampling points on each floodplain and at three different soil depths 0-35, 35-70, 70-105 cm. Soil parameters were determined using standard laboratory procedures; Particle size distribution (Gee and Bauder, 1986)[12], soil organic carbon (Nelson and Sommers, 1982)[20], Electrical conductivity (Piper, 1942[24]; Rayment and Higginson, 1992[25]), effective cation exchange capacity (ECEC) by summation (Black, 1965)[6]. pH (Bates, 1954) [5], available phosphorus (Bray and Kurtz, 1945)[8] and P in solution (Murphy and Riley, 1962)[19]. There was a significant positive correlation between soil available P and pH (r = 0.525 P = .05), supported by a significant negative correlation between E.A and available P (r = - 0.604* P = .05). The soils manifest high significant negative correlation between soil available P and Ca^{2+} as well as ECEC (r = - 0.586** P < 0.01). Thus, Soil solution pH, exchangeable acidity (H^{+}+Al^{3+}), calcium ions Ca^{2+} and ECEC were the major soil properties that controls P availability in Hadejia-Nguru floodplains.*

Key Words: Correlation, Soil Properties, Sorption, Floodplains, Phosphate Availability.

1.1 INTRODUCTION

Soil physical and chemical properties such as; clay content, organic matter (O.M), cation exchange capacity (C.E.C) and soil pH affect phosphate availability greatly (Hamoud, *et al.* 2024)[14]. Soils with high clay content have a greater capacity to loosely adsorb and retain P making it potentially available for plant uptake (Yan, *et al.* 2020[29]; Hamoud, *et al.* 2024[14]; Chen, and Arai, 2024[9]). High clay content and/or Organic matter (OM) increases soil Cation Exchange Capacity (CEC) (Hamoud, *et al.* 2024)[14]. and higher CEC contributed from O.M can enhance P availability greatly (Antonangelo, *et al*. 2024[4]; Hamoud, *et al.* 2024)[14], due to its chelating ability (Orji *et al.* 2023) [23]. The naturally synthesized hydroxyl and carboxyl ligands in the humic, fulvic and low-molecular weight organic acids affect phosphate availability by being attracted to some of the reactive sites on the soil matrix surfaces thereby reducing strong P fixation (Ahmed *et al.* 2023[2]; Li, *et al.* 2024) [18]. The concentrations of $H_2PO_4^-$ and HPO_4^{2-} in the soil largely depends on soil solution pH (Johan, *et al.* 2021)[15]. The objectives of this research were to evaluate the impact of selected parameters controlling phosphorus availability in Hadejia-Nguru Floodplains. The major problem associated to flooded soils is formation of acidity due to aluminum hydrolysis and transformation of iron (III) in to Iron (II) which reacts with phosphate ions and make them un-available for plants uptake, where this problem exists organic matter application can help solve or reduce the problem by complexing and blocking the reactive sites of Al^{+3} and Fe^{+2} ions thereby inhibiting strong fixation of P ions on the aluminum and iron ions and make the P ions readily free in solution. Most of the recent researches (Goni, *et al*. 2022; Mohammed, *et al.* 2024) conducted in Hdejia-Nguru floodplains focus more on fertility status, pH, exchangeable bases and CEC of the wetlands. Hence, the need for this research to close the gap.

2.1 MATERIALS AND METHODS

2.1.1 Site Description

The research was conducted in Hadejia-Nguru floodplains in Sudan savanna of Nigerian. Three different floodplains namely northern floodplains located at 12.450°N and 10.044°E, western floodplains 12.405°N and 10.100°E and southern floodplains 12.447°N and 10.130°E of the Hadejia-Nguru river basin were selected. Disturbed soil samples were collected using W-shaped sampling strategy at three different sampling points and three different soil depths 0-35, 35-70, 70-105 cm from each of the floodplains, then composited to a total of 9 samples. The soil samples were air dried in the laboratory, crushed, passed through 2mm mesh sieve, labeled and stored in dark polyethene leathers for further laboratory analysis. Statistical package Software version 9.3. SAS (2011) [27] was use for the data analysis

2.1.2 Extraction and Analytical Procedures

Statistical package Software version 9.3.SAS The following procedures were used for the soil physical and chemical analysis; Particle size distribution using (Bouyoucos (1951) [7]; Gee and Bauder, 1986)[12], soil organic carbon (Nelson and Sommers, 1982)[19], Electrical conductivity (E.C) 1:2.5 soil/water ratio (Piper, 1942[23]; Rayment and Higginson, 1992)[24], Exchangeable bases and acidity were extracted using Ag-Thiourea single extraction method, exchangeable bases (K^+ and Na^+) were determined using flame photometer, (Mg^{++} and Ca^{++}) were determined using AAS. Exchangeable acidity (H^+ and Al^{+++}) were determined by titration method and finally ECEC was estimated by summing up exchangeable bases and exchangeable acidity (Black, 1965)[6]. Soil solution pH 1:2.5 was determined using (Bates, 1954)[5], Soil available phosphorus was extracted using Bray No1. (Bray and Kurtz, 1945)[8] and the P in solution was analyzed using the procedure of (Murphy and Riley, 1962)[19].

3.1 RESULTS AND DISCUSSION

3.1.1 Soil Clay Content

The statistical data obtained revealed that, the soil clay content (Table 1.0 and 2.0) recorded in the floodplains were within the range of 10 to 28 % clay. Soils with the highest clay contents were recorded in the surface soils of the southern and northern floodplains (Table 1.0 and 2.0) having 26 and 28 % clay. Consistent increase down the soil profile was observed in all the floodplains except in northern floodplain.

Table 1: The Particle-Size Distribution of Hadejia-Nguru Floodplains

Sampling Locations	Depth (cm)	% Clay	% Silt	% Sand	Textural Class
NFpHJRB	0-35	14.00	51.00	35.00	Silt loam
	35-70	14.00	35.00	52.00	Loam
	70-105	12.00	38.00	50.00	Loam
WFpHJRB	0-35	26.00	31.00	43.00	Loam
	35-70	16.00	32.00	52.00	Loam
	70-105	13.00	25.00	62.00	Loamy sand
SFpHJRB	0-35	28.00	28.00	44.00	Clay loam
	35-70	20.00	22.00	58.00	Sandy loam
	70-105	10.00	39.00	51.00	Loam

N = northern, W = western, S = southern, Fp = Floodplain, HJRB = Hadejia-Jama’are river basin

Table 2: Selected Soil Physical and Chemical Properties of Hadejia-Nguru Floodplains

Loc.	Depth(cm)	%Clay	O.C	pH $CaCl_2$	EA	Ca^{2+}	Mg^{2+}	K^+	Na^+	ECEC	EC(dSm^{-1})	Av.P
			(gkg^{-1})		(cmol(+)k g^{-1})							($mgkg^{-1}$)
NF	0-35	14	5.2	5.0	0.9	0.35	0.34	0.017	1.02	2.68	1.02	19.6
	35-70	14	4.1	5.1	0.9	0.77	0.40	0.017	1.03	3.17	1.21	14.2
	70-105	12	2.9	4.8	1.0	0.51	0.31	0.010	0.97	2.79	0.57	12.4
WF	0-35	26	7.7	5.1	1.3	0.35	0.35	0.011	1.24	3.45	1.02	16.2
	35-70	16	4.6	5.1	1.1	0.71	0.43	0.026	0.90	3.26	0.92	14.6
	70-105	13	2.9	4.4	1.3	0.55	0.22	0.019	1.14	3.00	0.89	10.5
SF	0-35	28	2.5	4.1	1.3	0.35	0.32	0.012	1.10	3.09	0.99	13.4
	35-70	20	1.9	5.3	0.9	0.66	0.41	0.017	0.90	3.04	0.86	9.4
	70-105	10	1.5	4.1	1.1	0.60	0.33	0.018	0.87	2.08	0.87	8.0

Loc.= Location**, NF =** Northern Floodplains, **WF =** Western Flood Plains, **SF =** Southern Floodplains,

SiL = Silt Loam, **SL** = Sandy Loam, **LS =** Loamy Sand, **L** = Loamy Soil, **CL** = Clay Loam

3.1.2 Soil Organic Carbon

The soil organic carbon of the floodplains was within the range of 1.5 to 7.7 gkg^{-1}. All the floodplains reveal drastic decrease down the profile. Surface soils of northern and western floodplains have higher organic carbon content (5.2 and 7.7) compared to the southern flood plain with (2.5) and similar trend was observed in all the three soil depths with southern flood plain having very low organic carbon content.

3.1.3 Soil Solution pH

The pH of the floodplains (Table 2.0) varied between strongly acidic (pH 4.1) to moderately acidic (pH 5.5). Southern flood plain has low pH 4.1 compared to northern and western floodplains (pH 5.0 and 5.1). Mohammed, *et al*. (2024)[21] reported a pH of 5.7 in Hadejia-Jama'are soils which corroborate with some of the values recorded in this work.

3.3.4 Exchangeable Acidity (EA)

The floodplains appeared to have a range of EA values between 0.9 to 1.3 $cmol_{(+)}kg^{-1}$. All the floodplains manifest increase in E.A down the soil profile except southern floodplain that manifest an inconsistent pattern. Shehu *et al.* (2015)[26] reported values < 1.0 $cmol_{(+)}kg^{-1}$ in Nigeria Sudan savanna which agree with the values recorded in this work.

3.1.5 The Exchangeable Calcium (Ca^{2+})

The Ca^{2+} content of the floodplains were within the range of 1.11 to 8.20 $cmol_{(+)}kg^{-1}$ which is generally low. Abdu and Udofot (2015)[1] shows that, Ca is a dominant cation in the exchange site of savanna drylands. Goni, *et al.* (2022)[13] reported 1.240 meq/L in the same wetlands of Hadejia-Jama'are. Shehu *et al.* (2015)[26] reported 2.0 to 5.0 $cmol_{(+)}kg^{-1}$ in dryland soils. Mohammed, *et al.* (2024)[21] reported a range of values of 3.44 to 4.31 $cmol_{(+)}kg^{-1}$ in Hadejia-Nguru wetlands, Nigeria.

3.1.6 The Exchangeable Magnesium (Mg^{2+})

The exchangeable magnesium concentration recorded in the floodplains ranged between 0.38 to 2.65 $cmol_{(+)}kg^{-1}$. Values obtained in all the locations were between low to moderate, since values ≤ 0.4 $cmol_{(+)}kg^{-1}$ is considered low (Leo *et al.* n.d[17] ; Daniel *et al*. 2016)[10]. Mohammed, *et al.* (2024)[21] reported a range of values of 1.752 to 2.158 $cmol_{(+)}kg^{-1}$ in Hadejia-Nguru wetlands, Nigeria, their report agree with the values recorded in this research work. Shehu *et al.* (2015)[26] reported a range of 0.3 to > 1.0 $cmol_{+}kg^{-1}$. some of the values he reported agree with the values recorded in this research work. Goni, *et al.* (2022)[13] reported 0.358 meq/L in the same wetlands of Hadejia-Jama'are.

3.1.7 The Exchangeable Potassium (K^{+})

Values obtained in the floodplains were generally very low 0.010 to 0.026 $cmol_{(+)}kg^{-1}$ attributed to non-exchangeable behavior of K^{+}, often trapped in the inter-layer of clay minerals, such that very little amount is freely available. Goni, *et al.* (2022)[13] reported values (1.1 meq/L) which were higher compared to the values obtained in this work. Mohammed, *et al.* (2024)[21] reported a range of values of 0.356 -0.692 $cmol_{(+)}kg^{-1}$ in Hadejia-Nguru wetlands, Nigeria, values reported in their work are higher than the values recorded in this work, the differences may be due to spacial variability of the soils even within the same environment as well as the sampling period.

3.1.8 The Exchangeable Sodium (Na^{+})

The exchangeable sodium concentration of the floodplains (Table 2.0) ranged from 0.87 to 1.24 $cmol_{(+)}kg^{-1}$. The soils manifest no evidence of sodicity, because for a soil to be considered sodic it must have exchangeable sodium percentage (ESP) >15 %, EC < 4 (dSm^{-1}), pH ≥8.2 and/or manifest visible effects on the soil structure (FAO, 2019)[11]. Shehu *et al.* (2015)[26] reported very low values (0.1 to 0.3 $cmol_{(+)}$ kg^{-1}) in Nigerian Sudan Savanna soils. Yakubu (2016)[29] reported 0.01 to 0.12 $cmol_{(+)}kg^{-1}$ in Nigerian Guinea Savanna. Mohammed, *et al.* (2024)[21] reported a range of values of 0.021 to 0.033 $cmol_{(+)}kg^{-1}$ in Hadejia-Nguru wetlands, these values are extremely low compared to the values reported in this research work.

3.1.9 Correlation of the Selected Soil Physical and Chemical Properties with Available P

The results obtained (Table 3.0) contains both positively and negatively significant correlation values between phosphate availability, soil physical and chemical properties. A significant positive correlation was observed between soil available P and soil solution pH (r = 0.525* $P < 0.05$) suggesting that soil available P will become readily available as pH improve from strongly acidic towards the neutral region and as the pH reversed to strongly acidic region available P will become more strongly tied-up and un-available for plants uptake. A significant positive correlation was observed between soil available P and OC content (r = 0.542* $P < 0.05$), this also shows that increase in OC content will leads to corresponding increase in P availability in the soil and vice-versa. Some researchers (Tsozue *et al.* 2016[28]; Amenkhienan, and Isitekhale, 2021[3]; Kadiri, *et al.* 2022)[16] reported significant positive correlations between available P and organic carbon in a Typic Dystrandept soils of Cameroon western highland (r = 0.87, $P < 0.05$), and on cretaceous sediments, shale and quaternary alluvium in Edo state, Nigeria (r = 0.980** $p < 0.01$) and also in different land use type of two agro-ecological zones of Nigeria respectively (r = 0.53 ** $P < 0.01$). A significant negative correlation was observed between available P and exchangeable acidity (H+Al) (r = - 0.604* $P < 0.05$). A high significant negative correlation was observed between available P and Ca^{2+} (r = - 0.630** $P < 0.01$). Reports by (Amenkhienan, and Isitekhale, 2021[3]; Ojorbor, and Aimufia, 2022)[22] reveal a high positive correlation between available P and Ca^{2+} ions in cretaceous sediments, shale and quaternary alluvium in Edo state, Nigeria (r = 0.969** p <

Table 3: Correlation Matrix of the Selected Soil Physical and Chemical Properties on Available Phosphorus

	Clay	pH $CaCl_2$	EC	Av.P	Na^+	K^+	Ca^{2+}	Mg^{2+}	H+Al	ECEC	OC
Clay											
pH	- 0.635** 0.0034										
EC	0.190	0.101									
Av.P	- 0.390	0.525* 0.0392	- 0.412								
Na^+	0.092	0.150	0.511* 0.0302	0.010							
K^+	- 0.029	- 0.189	- 0.401	- 0.048	0.009						
Ca^{2+}	0.685*** 0.0017	- 0.682*** 0.0018	0.559* 0.059	- 0.630** 0.0050	0.095	0.1803					
Mg^{2+}	0.450	0.313	0.006	0.204	0.188	- 0.100	- 0.177				
H+Al	0.582** 0.0112	0.910** 0.016	0.208	- 0.604* 0.0479	0.062	0.167	- 0.034	- 0.083			
ECEC	0.696*** 0.0013	- 0.624** 0.0056	0.119	- 0.586** 0.0106	0.294	0.348	0.970*** < 0.0001	- 0.081	0.098*** < 0.001		
OC	0.571*	0.442	0.370	0.442	0.055	0.430	-0.408	-0.209	-0.245	0.431	

EC = electrical conductivity, Av. p = available phosphorus, OC = organic carbon, ECEC = effective cation exchange capacity,

H+Al = hydrogen plus aluminum ions, pH = hydrogen ions potential of the soil solution. EC = electrical conductivity

0.01) and in Fadama soils of Asaba, Delta state, Nigeria, (r = 0.0665* $P < 0.01$). A high significant negative correlation was observed between available P and ECEC (r = - 0.586** $P < 0.01$) in Hadeja-Jama'are floodplains and in contrary, a very strong positive correlation was reported by (Amenkhienan, and Isitekhale, 2021)[3] r = 0.944** $P < 0.01$ on cretaceous sediments, shale and quaternary alluvium in Edo state, Nigeria. Soil clay content shows a very significant positive correlation with pH $CaCl_2$ (r = 0.635** $P < 0.01$), EA (r = 0.582** $P < 0.01$) and a very high significant positive correlation with ECEC (r = 0.696*** $P < 0.001$) and with Ca^{2+} (r = 0.685***). Electrical conductivity (EC) correlates significantly positive with Na^{+} (r = 0.511) and Ca^{2+} (r = 0.259*) while soil solution pH correlate negatively and very significantly negative with Ca^{2+} (r = - 0.682*** $P < 0.001$) but EA reveal very significantly negative correlation with pH, indicating that an increase in EA will consequently leads to corresponding decrease in soil solution pH and make the soil solution more acidic. A high significant positive correlation was observed between ECEC and Ca^{2+} content of the study area (r = 0.970*** $P < 0.001$), suggesting that an increase or decrease in Ca^{2+} content of Hadeja-Jama'are floodplains is directly proportional to ECEC.

4.1 CONCLUSION

Base on the data presented in this study, the following conclusions were made: Soil solution pH, exchangeable acidity (H^{+}+Al^{3+}), calcium ions Ca^{2+} and estimated cation exchangeable capacity ECEC were the major soil properties that controls P availability in Hadejia-Nguru floodplains as at the time this research was conducted, because the correlation matrix revealed a significant positive correlation between soil available P and pH (r = 0.525* $P = .05$), suggesting that soil P becomes more available as pH improve from strongly acidic towards the neutral region vice-versa. This was also supported by the significant negative correlation (r = - 0.604* $P = .05$) between E.A and available P, indicating that as E.A increases P availability decreases. The soils manifest high significant negative correlation between soil available P and Ca^{2+} ions as well as ECEC (r = -0.586** $P < 0.01$) indicating that, high amount of Ca^{2+} ions increase soil ECEC and an increase in ECEC will lead to increase in high P sorption. The soils of the Hadejia-Nguru floodplains were strongly to moderately acidic as at the time this research was conducted. The soils exhibit low clay content. The soils have very low exchangeable K^{+} associated to non-exchangeable behavior of K^{+} often trapped in the inter-layer of clay minerals.

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