Influence of Some Soil Physical and Chemical Properties Regulating Phosphate Availability in Hadejia-Jama'are Wetland Soils.

ABSTRACT

The objectives of this study were to examine the major soil routine parameters regulating P availability and transformation in Hadejia-Jama'are wetlands. Three wetland locations; Sinamu, Tandanu and Masama and their corresponding adjacent dryland soils as control were strategically selected. Six profile pits were dug (one each on the six research wetlands). Triplicate soil samples were collected strategically at 0-35, 35-70, 70-105 cm soil depths. The following standard laboratory procedures were used; Particle size distribution (Uyovbisere, et al. 2013)[28], soil organic carbon (SSSA, 2016)[23], Electrical conductivity (Rhoades, and Manteghi, 2018[21]), effective cation exchange capacity (ECEC) by summation (Soil Survey Staff (2017)[24], pH (Brevick, and Burgess, 2021)[4], available phosphorus (Sparks, 2021)[25]. The clay content of the soils manifest decrease from top to bottom except in Sinamu and Tandanu upland soils. The pH of the wetland soils varied between strongly acidic (pH 4.1) to moderately acidic (pH 5.5) while that of the drylands varied between moderately acidic (pH 5.3) to slightly acidic (pH 6.8). There is significant difference in soil solution pH and

exchangeable acidity between the two land forms P = .05. The wetland have higher EA values 0.9 to 1.3 cmol$_{(+)}$kg^{-1} compared to dryland soils 0.4 to 0.6 cmol$_{(+)}$kg^{-1}. There was a significant difference Mg^{2+} content between the wetlands and the drylands (P =.05). The values of Potassium ions recorded were generally very low both in the wetlands 0.010 to 0.026 cmol$_{(+)}$kg^{-1} and the drylands 0.02 to 0.036 cmol$_{(+)}$kg^{-1}. There was significantly difference P = .05 between the wetland and dryland soils with the dryland soils having higher Ca^{2+} ions. The difference in effective cation exchange capacity (ECEC) between the wetland and the dryland soils was statistically significant P = .05 with the dryland soils having higher ECEC values. there was significant difference in ECEC between the surface soils 0 to 35cm and the sub-surface soils 35cm up to 105 cm P = .05. The available P content of the two land forms were significantly different P = .05. Base on the findings above, the soil parameters regulating P availability and transformation in both Hadejia-Jama'are wetland and dryland soils in order of increasing magnitude are silicate clays, pH, O.C, ECEC, EA, Ca and Mg.

Key words: Wetlands, Phosphate, Clay Content, Organic Matter, pH.

1.1 INTRODUCTION.

The reaction types that fix P ions in soils varies from soil to soil and have strong connection to soil solution pH. High P fixation occur at a very low or very high soil solution pH (Hamoud, *et al.* 2024)[13]. The concentrations of $H_2PO_4^-$ and HPO_4^{2-} in soil largely depends on the soil solution pH (Ducousso-Detrez, *et al.* 2022)[7]. Soil clay content affect P sorption by attracting P ions onto smaller clay particles such as free Fe and Al oxides, thus soils with high clay content tend to have high P fixing capacity (Goyal and Sigh 2020)[11]. Soil organic matter (O.M) greatly influences P sorption-desorption through its binding effect (Leinweber, *et al.* 2023)[18]. The chelating ability of the naturally synthesized oxyl, hydroxyl and carboxyl

ligands synthesized by microbes from soil organic matter can affect phosphate availability by blocking some of the reactive sites on the soil matrix surfaces thereby reducing phosphate adsorption (Ahmed, *et al.* 2023)[1]. Humic acids on their own have the ability to inhibit crystallization and polymerization of Fe and Al oxides (Khundzhua, *et al.* 2020)[15]. High clay content and high O.M in soil have the potential to increase the soil cation exchange capacity CEC (Goyal and Sigh 2020)[11]. The greatest problem of available phosphorus (P) in soil is that P can be sufficiently present yet un-available for plants uptake due to strong covalent bond formed with aluminum/iron oxides and/or undergo precipitation reaction with calcium and magnesium ions in the soils readily. Lack of knowledge about this problem by farmers, makes lots of farmers to apply excess amount of P source in an attempt to replenish the soil P in order to achieve bumper harvest which in turn leads to eutrophication of the wetland water bodies and rapid growth of invasive species of grasses that claims many of the suitable portions of the wetlands used for crops cultivation. In situations where this problem exist, application of sufficient organic matter can help solve or at least reduce the problem to a minimum level, otherwise liming can be recommended if the problem is severe. As at when this research was carried out, no research was conducted to specifically examine the parameters controlling P availability in Hadejia-Jama'are wetland and its dryland soils. Most of the established researches; Aliyu, *et al.* (2022)[3] limit their findings to pedogeochemical assessment of the Hadejia- Jama'are wetlands which is non-specific to P and/or parameters controlling P availability in soils, Goni, *et al.* (2022)[10] limit their findings to exchangeable bases of the Hadejia-Jamaare wetlands, Umar, *et al.* (2023)[27] limit their findings to land use and Mohammed, *et al*. (2024)[19] limit their findings to statistical assessment of pH, exchangeable bases and base saturation of Hadejia-Nguru wetland soils.

2.1 MATERIALS AND METHODS

2.1.1 Site Description:

Three wetland locations, namely; northern wetlands, western wetlands, southern wetlands of Hadejia-Jama'are river basin and their corresponding adjacent drylands as control were strategically selected. The sampling locations and coordinates of the sampling point were; Sinamu wetland at 12.450°N and 10.044°E, Sinamu dryland at 12.455°N and 10.054°E, Tandanu wetland at 12.405°N and 10.100°E, Tandanu dryland at 12.452°N and 10.110°E, Masama wetland at 12.447°N and 10.130°E, Masama dryland at 12.501°N and 10.111°E.

2.1.2 Sampling. A total of six profile pits were sank, one on each of the six research wetlands. Triplicate undisturbed and disturbed soil samples were collected at each of the selected soil depths 0-35, 35-70, 70-105 cm. The soil Samples collected were immediately transferred into air-sealed plastic bags, labeled appropriately and transported to the laboratory.

2.1.3 Treatment of the samples.

The undisturbed soil samples collected were used for bulk density analysis while the disturbed soil samples were air dried, crushed, sieved through 2mm mesh sieve, labeled and stored in polythene lathers for particle-size-distribution and further laboratory chemical analyses. Grade analytical reagents and distilled water were used all through the laboratory experiments. All the glass wares and plastic containers used were washed with detergent, swirl with nitric acid, then rinsed very well with distilled water.

2.1.4 Analytical procedures/Instrumentations.

The following standard laboratory procedures were employed; Bulk density analysis (Lal, (2021)[16]. Particle size distribution was determined by the Bouyoucus standard hydrometer method described by (Uyovbisere, *et al.* 2013)[28]. Soil organic carbon content was

determined using Walkley-Black method described by (SSSA, 2016)[23] and calculated using the formula

$$\% \text{ OC} = \frac{\text{Blank - Titter x NF x 0.003 x CF}}{\text{Weight of the soil sample used}} \times 100$$ and finally converted to gkg^{-1} as % OC x 10.

The soil pH was determined using Advance (m/v) digital pH meter in 1:2.5 soil/deionized water described by (Brevick, and Burgess, 2021)[4]. Effective cation exchange capacity (ECEC) was determined using ammonium acetate method described by (Soil Survey Staff, 2017)[23]. Electrical conductivity was determined in 1:2.5 soil/water ratio using (Rhoades, and Manteghi, 2018)[21] procedure. Available P was determine using Bray 1 procedure described by (Sparks, 2021)[25]. Data obtanine was subjected to ANOVA using Statistical Analysis System SAS (2011)[26]. Statistical Software package version 9.3

3.1 RESULTS AND DISCUSSION

The clay content and the textural class (Table 1.0 and 2.0) recorded in the wetland soils ranged between 10 to 28 % clay while in the dryland soils a range of 9 to 12 % clay was recorded. The textural class of the wetland soils varied from silt loam, loam, loamy sand, sandy loam and clay loam while that of the dryland soils were dominantly sandy loam and loam. Out of the eighteen soil samples, eight were classified as loamy soils, seven sandy loam, one silt loam, one loamy sand and one clay loam. The clay content recorded in the wetlands reveal higher values compared to the drylands, having dominant clay values between 14 and 28 % (Table 2.0). The dryland soils manifest very low clay content, having dominant clay values between 9 to 12 % clay. Consistent increase in clay content down the soil profile was observed in all the wetlands except the northern wetland. On the other hand, the dryland soils manifest consistent decreases from surface to sub-surface except in southern dryland. A significant difference $P = .05$ in clay content (Table 2.0) between the wetland and the dryland soils was observed and the highest mean value was recorded in the wetland soils. The bulk density values across the three wetlands were found slightly higher 1.40 to 1.56 gcm^{-3} compared to those recorded in the dryland 1.40 to 1.54 gcm^{-3} revealing the true nature of a wetland's geology. The BD from 70 cm downward manifest some evidence of compaction. However, values reported were in conformity with those recorded by (Aliyu *et al.* 2022)[3] 1.53 gcm^{-3} in Hadejia-Jama'are wetland soils. The pH of the wetland soils (Table 2.0) varied between strongly acidic (pH 4.1) to moderately acidic (pH 5.5) while the dryland pH varied between moderately acidic (pH 5.3) to slightly acidic (pH 6.8). Masama upland appeared to be more acidic compared to Sinamu and Tandanu uplands. The wetland soils also manifest similar trend, suggesting that, soil properties down-slope are usually a reflection of the soil properties up-

Table 1.0 Particle-Size Distribution of Hadejia-Jama'are Wetlands and Dryland Soils

Sampling Locations	Depth (cm)	% Clay	% Silt	% Sand	Textural class
			WETLANDS		
SINAMU	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
TANDANU	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
MASAMA	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
			DRYLANDS		
SINAMU	0-35	11.00	37.00	52.00	Loam
	35-70	10.00	21.00	69.00	Sandy loam
	70-105	9.00	32.00	59.00	Sandy loam
TANDANU	0-35	11.00	29.00	60.00	Sandy loam
	35-70	11.00	30.00	59.00	Sandy loam
	70-105	10.00	38.00	52.00	Loam
MASAMA	0-35	12.00	38.00	50.00	Loam
	35-70	9.00	24.00	67.00	Sandy loam
	70-105	10.00	15.00	75.00	Sandy loam

slope. The wetland soils are generally acidic compared to the dryland soils, indicating abundance of soluble aluminum and hydrogen ions and probably manganese in that pedo-environment. This might be as a result of anaerobic condition of the wetlands and the lithologic origin of the parent material from which weatherable materials were washed, transported and deposited down-slope. All the drylands show decrease in pH down the soil profile except in Tandanu dryland. Aliyu, *et al.* (2022)[3] reported a pH of 4.88 in Hadejia-Jama'are wetland soils which corroborate with the values recorded in this work. Shehu *et al.* (2015)[22] obtained a pH range of 5.0 to 5.5 in Sudan savanna soils which also corroborate with the values observed in the upland soils in this work. There is however, significant difference in soil solution pH (Table 3.0) between the two land forms P = .05, suggesting dominance of soluble aluminum in the wetland soil solution. There was significant difference in soil solution pH between the surface (0-35cm) and subsurface (70-105cm) but the two selected soil depths mentioned above were statistically the same with the sub-surface (35 to 70 cm) soil depth at P = .05. This may be attributed to leaching of soluble products within 0 to 70 cm soil depth. There is significant interaction in pH between the land forms and the selected soil depths (Table 5.0).

3.1.1 Exchangeable Acidity (EA)

The wetland soils appeared to have higher EA values 0.9 to 1.3 $cmol_{(+)}kg^{-1}$ compared to dryland soils 0.4 to 0.6 $cmol_{(+)}kg^{-1}$. Similarly, there is a significant difference (P = .05) (Table 3.0) in exchangeable acidity between the two land forms probably due to protonation by hydrogen ions from water molecule and soluble aluminum ions released from the parent rock, trapped and incorporated into the soil and became part of the clay mineralogy, there by changing the composition of the soil-mineral. All the wetlands showed increasing E.A down the soil profile except southern wetland that manifest an inconsistent pattern. Shehu *et al.* (2015)[22] reported

values < 1.0 $cmol_{(+)}kg^{-1}$ in Nigeria Sudan savanna which agree with the values recorded in this work.

3.1.2 The Exchangeable Sodium (Na^+)

Exchangeable sodium concentration of the wetland soils (Table 2.0) ranged from 0.87 to 1.24 $cmol_{(+)}kg^{-1}$ while values obtained in the dryland soils ranged from 0.16 to 1.08 $cmol_{(+)}kg^{-1}$. The soils have no evidence of sodicity, since 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)[8]. Shehu *et al.* (2015)[22] 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. All the values cited here were low compared to the values reported in this work

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

The exchangeable magnesium concentration recorded in the dryland soils is higher 0.22 to 0.51 $cmol_{(+)}kg^{-1}$ compared to 0.38 to 2.65 $cmol_{(+)}kg^{-1}$ observed in the wetland soils and there is a significant difference (P = .05) Mg^{2+} content between the wetland and the dryland soils (Table 3.0). Values obtained in both locations especially in the dryland soils were between low to moderate, since values < 0.3 even up to 0.4 $cmol_{(+)}kg^{-1}$ can still be considered low (Leo *et al.* n.d[] ; Daniel *et al*. 2016)[6]. Shehu *et al.* (2015)[22] 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 work.

3.1.4 The Exchangeable Potassium (K^+)

Values obtained were generally very low both in the wetlands 0.010 to 0.026 $cmol_{(+)}kg^{-1}$ and 0.02 to 0.036 $cmol_{(+)}kg^{-1}$ in the drylands, attributed to non-exchangeable behavior of K^+, often trapped in the inter-layer of clay minerals, such that only very little amount is freely available. Shehu *et al.*

Table 2.0 Selected Soil Physical and Chemical Properties of Hadejia-Jama'are Wetlands

Loc.	Depth(cm)	BD (gcm^{-3})	Clay %	T/class	pH $CaCl_2$	EA	Na^+	Mg^{2+}	K^+	Ca^{2+}	ECEC	EC(dSm^{-1})	Av.P ($mgkg^{-1}$)	OC (gkg^{-1})
						(cmol(+)k g^{-1})								
SN	0-35	1.45	14	SiL	5.0	0.9	1.02	0.34	0.017	0.35	2.68	1.02	19.6	5.2
	35-70	1.46	14	L	5.1	0.9	1.03	0.40	0.017	0.77	3.17	1.21	14.2	4.1
	70-105	1.49	12	L	4.8	1.0	0.97	0.31	0.010	0.51	2.79	0.57	12.4	2.9
TA	0-35	1.54	26	L	5.1	1.3	1.24	0.35	0.011	0.35	3.45	1.02	16.2	7.7
	35-70	1.54	16	L	5.1	1.1	0.90	0.43	0.026	0.71	3.26	0.92	14.6	4.6
	70-105	1.44	13	LS	4.4	1.3	1.14	0.22	0.019	0.55	3.00	0.89	10.5	2.9
MA	0-35	1.56	28	CL	4.1	1.3	1.10	0.32	0.012	0.35	3.09	0.99	13.4	2.5
	35-70	1.40	20	SL	5.3	0.9	0.90	0.41	0.017	0.66	3.04	0.86	9.4	1.9
	70-105	1.54	10	L	4.1	1.1	0.87	0.33	0.018	0.60	2.08	0.87	8.0	1.5

Loc.= Location**, SIN =** Sinamu , **TA =** Tandanu, **MA =** Masama, **SiL =** Silt Loam, **SL** = Sandy Loam, **LS =** Loamy Sand, **L** = Loamy Soil, **CL** = Clay Loam

Table 3.0 Contenued Selected Soil Physical and Chemical Properties of Hadejia-Jama'are Drylands

Loc	Depth (cm)	Bd (gcm^{-3})	Clay %	T.class	pH $CaCl_2$	EA	Na^+	Mg^{2+}	K^+	Ca^{2+}	ECEC	EC (dSm^{-1})	A.P (mgkg-1)	O.C gkg^{-1}
								($cmol(+)kg^{-1}$)						
SN	0-35	1.45	11	L	6.8	0.4	0.93	0.76	0.036	3.18	5.33	1.81	16.6	5.6
	35-70	1.40	10	SL	5.6	0.5	1.07	0.73	0.028	3.14	5.52	1.91	10.6	4.6
	70-105	1.46	9	SL	5.5	0.5	0.16	0.57	0.002	1.29	2.52	1.24	12.1	3.9
TA	0-35	1.49	11	SL	6.0	0.4	0.96	0.38	0.035	5.50	8.29	2.11	13.5	5.8
	35-70	1.45	11	SL	6.1	0.5	1.04	0.75	0.031	8.80	11.10	2.01	11.5	5.6
	70-105	1.54	10	L	6.2	0.4	1.08	1.08	0.002	6.20	8.76	1.18	10.0	5.0
MA	0-35	1.46	12	L	5.6	0.5	1.05	1.18	0.036	1.11	4.00	1.95	16.0	5.0
	35-70	1.54	9	SL	5.5	0.6	0.93	0.60	0.028	2.44	4.65	1.10	10.9	4.6
	70-105	1.42	10	SL	5.5	0.4	0.99	2.65	0.002	1.44	5.48	1.00	11.1	2.9

Loc. = Location, **SN** = Sinamu , **TA** = Tandanu, **MA** = Masama, **LS** = Loamy Sand, **L** = Loamy Soil,

Table 4.0 Effect of Treatments on Selected Soil Physical and Chemical Properties in Hadejia-Jama'are River Basin

Trt.	Bd	Clay	pH	EC	OC	TN	ECEC	E.A	Na^+	K^+	Ca^{2+}	Mg^{2+}	Av.P
	(gcm^{-3})	gkg^{-1}	$CaCl_2$	(dSm^{-1})	(gkg^{-1})		($cmol(+)kg^{-1}$)						($mgkg^{-1}$)
Land forms													
Wetlands	1.492	16.67^{a}	4.68^{b}	1.23	4.8	2.83	4.29^{b}	2.081^{a}	1.01	0.019	0.94^{b}	0.49^{b}	13.19^{a}
Drylands	1.469	10.33^{b}	6.03^{a}	2.20	3.7	3.14	8.82^{a}	0.993^{b}	0.91	0.022	2.68^{a}	1.37^{a}	11.70^{b}
LSD	0.0595	5.171	1.03	1.44	1.4	0.81	1.197	0.79	0.23	0.0095	0.82	0.35	1.205
Location													
Sinamu	1.453	14.88	5.38	2.03	4.4^{ba}	2.85	6.02^{a}	1.230	0.86	0.018	1.04^{b}	0.54	14.25^{a}
Tandanu	1.500	14.00	5.73	1.21	5.3^{a}	2.85	7.52^{a}	1.138	1.04	0.024	3.19^{a}	0.67	12.88^{ab}
Masama	1.488	11.07	5.38	1.20	3.1^{b}	3.27	4.63^{b}	1.023	0.97	0.018	0.90^{b}	0.54	11.70^{b}
LSD	0.073	0.33	0.59	2.04	1.7	0.99	2.66	1.335	0.28	0.012	0.99	1.65	1.333
Depth (cm)													
0-35	1.492	15.83	5.92^{a}	2.18	3.8	3.87^{a}	5.48^{a}	1.535	0.87	0.009^{b}	1.60^{b}	1.38	15.55^{a}
35-70	1.468	13.33	5.70^{ab}	2.20	4.3	2.63^{b}	3.06^{ab}	0.822	0.98	0.025^{a}	2.92^{a}	0.60	11.87^{b}
70-105	1.482	11.33	5.20^{b}	1.22	4.7	2.47^{b}	4.62^{a}	1.035	1.03	0.028^{a}	1.31^{b}	0.56	11.42^{b}
LSD	0.073	6.33	0.59	2.04	1.7	0.99	2.26	1.335	0.28	0.012	0.99	1.65	2.33
Interactions													
Lf x Loc	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS	*
Lf x Dth	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Loc x Dth	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LfxLocxDth	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Lf = Landform, **Loc =** Location, **Dth** = Depth, **Trt =** Treatments

Table 5 Interaction of Land Forms by Locations on ECEC, Ca^{2+} and Av.P

	ECEC (cmol(+)kg^{-1})			Ca^{2+} (cmol(+)kg^{-1})			Av.P (mgkg^{-1})		
Locations	Sinamu	Tandanu	Masama	Sinamu	Tandanu	Masama	Sinamu	Tandanu	Masama
Wetlands	8.82^{ab}	12.97^{a}	8.04^{b}	3.08^{b}	3.07^{b}	3.07^{b}	14.41^{ab}	23.06^{ab}	27.28^{a}
Uplands	6.34^{b}	7.08^{b}	6.96^{b}	5.76^{ab}	8.78^{a}	4.24^{ab}	9.11^{b}	24.01^{ab}	22.99^{ab}
SE±	1.99	1.99	1.99	2.24	2.24	2.24	7.82	7.82	7.82

Table 6.0 Interaction of Landforms and Selected Soil Depths on pH $CaCl_2$.

Depth (cm)	Sinamu	Tandanu	Masama
Wetlands	5.467^{b}	5.433^{b}	5.967^{a}
Uplands	5.267^{b}	6.10^{a}	5.467^{b}
SE±	0.197	0.197	0.197

(2015)[22] reported very low values (< 0.15) which were still higher compared to the values obtained in this work. Values reported in Hadejia-Jamaare wetlands 0.41 to 16.07 mg kg^{-1} by Goni *et al.* (2023)[10] were extremely low compared to the values recorded in the same wetland soils of Hadejia-Jama'are river basin, probably associated to the difference in seasons within the year when the soil sampling was established. The K^+ content between soil depth 35 to 70 cm and 70 to 105 cm were statistically the same (P = .05) but significantly different with the K^+ content at soil depth 0 to 35 cm. The K fixation in the interlayer of the clay minerals is probably high at soil depth 35 to 105 cm than at soil depth 0 to 35 cm.

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

The Ca^{2+} concentration in the dryland soils appeared to be much higher 0.35 to 0.77 $cmol_{(+)}kg^{-1}$ compared to 1.11 to 8.20 $cmol_{(+)}kg^{-1}$ in the wetland soils despite high clay content was observed in the wetland soils. Probably due to low EA and high pH observed in the dryland soils. Abdu and Udofot and Abdu, (2015)[2] reported that, Ca is the dominant cation in the exchange site of savanna drylands. Shehu *et al.* (2015)[22] reported 2.0 to 5.0 $cmol_{(+)}kg^{-1}$. There is significantly difference P = .05 between the wetland and dryland soils with the dryland soils having higher Ca^{2+}. The Ca^{2+} content between the soils of Sinamu and Masama locations were statistically at par P = .05 but significantly different from the Tandanu research location. The distribution pattern down the soil profile showed no significant difference P = .05 between the two soil depths 0-35 cm and 70-105 cm but was significantly different from 35 to 70 cm soil depth P = .05 indicating presence of a bleached zone somewhere within 35 to 70 cm soil depth, attributed to co-migration of Ca with clays especially in the wetland soils during the period of heavy downpour usually in the month of August and due to continuous push by irrigation water during the dry season irrigation activities by farmers. There was significant interaction between landforms and research locations

(Table 4.0) The highest ranked Ca^{2+} interaction between land form and research locations (Table 4.0) was recorded at Tandanu upland but it wasn't significantly different from values recorded in Sinamu and Masama dryland soils. However, it was significantly different from Ca^{2+} values obtained due to the effect of interaction between landform and research locations in all the wetland soils. Similarly, effect of interaction recorded at Sinamu and Masama drylands was statistically the same with the Ca^{2+} value recorded in all the wetland soils, attributed to sharp variation in calcium content between the two land forms, across the research fields and down the soil sampling depths**.**

3.1.6 The Effective Cation Exchange Capacity (ECEC)

The ECEC (Table 2.0) ranged from 2.68 to 3.40 $cmol_{(+)}kg^{-1}$ in the wetland soils and 2.52 to 11.10 $cmol_{(+)}kg^{-1}$ in the dryland soils. Values observed in the dryland soils appeared to be higher compared to values observed in the wetland soils. High concentration of exchangeable calcium recorded in the dryland soils may explain this difference. The soil ECEC recorded, show increase from surface to sub-surface in the drylands except in Tandanu dryland while in the wetland soil, the distribution is almost uniform with little variation from 0 up to 105 cm soil depth. Values up to 7.22 $cmol_{(+)}kg^{-1}$ were reported by (Aliyu *et al.* 2022[3]; Umar *et al.* 2023)[27] in wetland soils. The difference in effective cation exchange capacity (ECEC) between the wetland and the dryland soils (Table 3.0) was statistically significant $P = .05$, with the dryland soils having higher ECEC values attributed to abundance of Ca ions as earlier observed in the soil physicochemical properties, which contribute greatly to the ECEC values compared to contribution by other exchangeable cations, indicating high tendency for P precipitation in the drylands by Ca ions under high pH than there will be in the wetlands. However, across the three research locations, the ECEC in Sinamu and Tandanu soils were statistically the same but significant difference exist between

Masama and the two other locations above all at $P = .05$, having Sinamu and Tandanu soils with higher ECEC values compared to Masama soil, suggesting that, Masama soils may have probably been formed from a different parent material, different from Sinamu and Tandanu soils. It may probably be attributed to calcium loading from calcium phosphate fertilizer added by farmers or from organic manure added by farmers prior and or during farming activities. There was no significant difference in ECEC from 70 cm up to 105 cm soil depth, but there was significant difference in ECEC between the surface soil 0 to 35cm and the sub-surface soil 35cm up to 105cm $P = .05$, this can be linked to difference in O.M content which is usually high in the surface soils of most soils than there is in the sub-surface soils. There was significant interaction between land forms and research locations (Table 3.0) attributed to profound variations revealed by clay content, organic carbon content, exchangeable acidity and exchangeable basis (Table 2.0). Highest ranked ECEC value due to interaction between land forms and research locations (Table 4.0) was recorded at Tandanu wetland but it was not significantly different from the value recorded at Sinamu wetland. However, it was significantly different from ECEC values obtained between land forms and locations at all the drylands and at Masama wetland. This may in addition be attributed to high E.A recorded in Tandanu and Sinamu wetlands which leads to serious increase in the ECEC of these two locations over Masama.

3.1.7 Electrical Conductivity (EC)

The electrical conductivity (EC) ranged from 0.57 to 1.21 dSm^{-1} in the wetland soils of the study area while 1.24 to 2.41 dSm^{-1} was recorded in the drylands (Table 2.0). It was obvious that the dryland soils manifest higher EC values compared to the wetland soils. This may suggest more soluble salts probably contributed by calcium and magnesium salts. The EC was more at the surface than the sub-surface soils, probably due to upward capillary movement that pushes soluble

salts and eventually got deposited or adsorbed to the soil particle surface. Umar, *et al.* (2023)[27] reported a range of 0.01 to 1.1 dSm^{-1} in savanna soils which was in harmony with the range of values obtained in this study. Mean values of the electrical conductivity (EC) were statistically the same $P = .05$ between the two land forms, across the three research locations and also down the three selected soil depths. All the interactions were non-significant $P = .05$.

3.1.8 Soil Organic Carbon (OC gkg^{-1})

The soil organic carbon in the wetland soils (Table 2.0) ranged from 1.5 to 7.7 gkg^{-1} while values observed in the dryland soils ranged from 2.9 to 5.8 gkg^{-1}. Values obtained are very low, since values less than 20 gkg^{-1} were generally considered low. Umar, *et al.* (2023)[27] reported a range of values from 1.0 to 7.8 gkg^{-1} in savanna soils. Values reported 6.3 to 127 gkg^{-1} by Aliyu, *et al.* (2023)[3] does not agree with the values reported in this work. The distribution pattern down the soil profile indicates consistent decrease from 0 up to 105 cm selected soil depths. Soil organic carbon content (OC gkg^{-1}) in the wetland soils and the dryland soils (Table 3.0) are statistically the same $P = .05$. The OC gkg^{-1} content between the three selected soil depths were also statistically the same $P = .05$. There was a significant difference in O.C gkg^{-1} between Tandanu and Masama research locations but the two locations were statistically the same with Sinamu research location all at $P = .05$.

3.1.9 Available Phosphorus (Av. P)

The available P in the wetland soils (Table 2.0) ranged from 8.0 to 19.6 $mgkg^{-1}$ and 10.0 to 16.6 $mgkg^{-1}$ was recorded in the dryland soils. Higher values observed in the wetlands may suggest deposition of organic materials and inorganic phosphate ions mobilized and transported from upslope into the wetlands via run-off water. However, values recorded were classified within low to very low, since values less than < 20 ppm can still be considered low (Chimdi *et al.* 2022)[5].

The distribution pattern down the soil profile revealed sharp decrease from surface to sub-surface soils across all the fields, suggesting that most of the P was concentrated at the surface soils in other words, available P decrease with increase in soil depth (Johnbosco, *et al. 2023*)[14]. Habib, *et al.* (2003)[12] reported available P of 2.17 $mgkg^{-1}$ in Ungogo, Kano, Sudan Savanna, Nigeria. Mohammeda, *et al.* (2024)[19] reported a range of 18.6 to 24.0 $mgkg^{-1}$. Orji, *et al.* (2023)[20] reported a range of 3.30 to 40.00 $mgkg^{-1}$. All the values reported above were in agreement with the values obtained from wetland and dryland soils in Hadeja-Jama'are river basin in this study. The available P content of the two land forms (wetlands and dryland soils) (Table 3.0) were significantly different $P = .05$, suggesting mobilization and import of several soluble products such as herbicides, pesticides, fungicides, soluble inorganic P from phosphate fertilizers and organic materials brought in by run-off from the drylands into the wetland areas. Supporting the general opinion that wetland soils are often characterized by accumulation of organic matter (Fu, *et al.* 2023)[9], in addition, much higher temperature in the agro-ecological zone of the research area, especially in the dryland areas may have contributed to this effect observed. The available P content of Sinamu and Masama research locations are significantly different ($P = .05$), but statistically the same with Tandanu research location ($P = .05$). The vertical spatial distribution of available P content down the soil profile indicates that, the selected surface soil (0 to 35 cm) was significantly different $P = .05$ from the sub-surface soils (35 to 70 cm and 70 to 105 cm). However, the two sub-surface soil depths (35 to 70 cm and 70 to 105 cm) were statistically the same $P = .05$ in available P content, giving more evidence the widely accepted opinion that P content in most soils is concentrated at the surface, usually 0 to 5 cm or 0 to 1 cm except in rare cases. There was significant interaction between the land forms and research locations (Table 3.0) probably due to variations in Fe and Al oxides associated to clay content, or variation in calcium and magnesium

content or variation in organic carbon content or combine. The highest ranked interaction (Table 4.0) was observed in Masama wetland and it was not significantly different from Sinamu, Tandanu wetlands and Tanadanu, Masama drylands, however there is significant difference in the interaction between Masama wetland and Sinamu drylands $P = .05$.

4.1 CONCLUSION

Base on the findings above, the soils parameters regulating P availability and transformation in both wetlands and dryland soils in the order of increasing magnitude include silicate clays, pH, O.C, ECEC, EA, Ca and Mg.

Base on the Statistical findings obtained, phosphate availability is higher in the wetlands of Hadejia-Jama'are than it is in the drylands suggesting deposition of organic materials and inorganic phosphate ions mobilized, transported from up-slope by run-off and deposited in to the wetland soils.

Phosphate ions were more available in Sinamu wetlands, moderately available in Tandanu wetlands and less available in Masama wetlands which cannot be unconnected to the low nature of organic carbon observed in Masama wetland soils compared to Sinamu and Tandanu wetland soils.

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