EVALUATION OF FADAMA SOILS ALONG A TOPOSEQUENCE PROXIMAL TO RIVER DONGA IN WUKARI AREA OF NORTHEAST NIGERIA.

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Abstract

The study was conducted to find out the variation in physical and chemical properties of fadama soils along a toposequence proximal to River Donga, Northeast Nigeria. Three mapping units were identified as crest, mid-slope and foot-slope. In each mapping unit, a profile pit was dug and soil samples were collected based on horizon differentiation. These soil samples were subjected to laboratory analyses using standard procedures. Data collected were analyzed statistically using analyses of variance and coefficient of variation. The particle size distribution showed the preponderance of sand followed by clay though clay increased down the profile. The soil is acidic with pH range of 5.02 to 6.66. Organic carbon recorded mean of 10.75 mg kg^{-1}, 9.03 mg kg^{-1} and 7.06 mg kg^{-1} for soils under crest, mid-slope and foot-slope, respectively. Silt, pH and C:N recorded low variation in all the mapping units whereas clay and total nitrogen recorded high variation. The toposequence considered have an influence on nutrient addition and enrichment. The soil can be very productive under good management with emphasis on restriction/controlled grazing activities.

Keywords: Fadama, Mapping units, Profile pit, River Donga, Toposequence

Introduction

The variation in rainfall patterns especially in the year 2015, as a year with the fewest amount of rainfall both in intensity and duration occasioned by climate change has further altered the reliance on fadama as a resource. Land has received wide attention for their potentials to improve food security and support socioeconomic wellbeing of rural dwellers. However, the ecosystem services and sustainability have been widely raised appropriate land-use and management pattern. Human activities on a fadama take place in a space which is influenced mainly by sediment accumulation and inundation by river floods. To predict future environmental development, land-use and planning management, it is essential to analyse and understand the past processes that led to recent condition (Damm, 2006). The constituents of landscape are slopes, if the development of individual slope is understood, the development of landscape can be synthesized (Scheidegger, 1961). The physical landscape is obviously no more than an assemblage of slopes and the dimensions and appearance of the slopes gives to an area its essential morphological character (Small, 1994). It is evident that the spatial-temporal susceptibility of morphodynamic processes depends on a long term development (Neuhauser and Terhorst, 2007). Hence, slope is a very complex feature which may not be described literally because of the processes involved in its formation. Topography as soil forming factor plays a major role in soil development. Its effects on soil formation involve the redistribution of elements.

The movement and transformation of nutrient in soils are influenced by climate and topography (Klemmedson and Weinhold, 1991). Seibert *et al.* (2007) reported significant correlation between topographic indices and soil properties while Temgoua et al. (2005) concluded that topography is both an internal and external factor in pedogenesis and accounted for about 60 % variation in soil properties (Cox *et al.*, 2002). The nutrient status and soil properties of fadama are related to its physiographic position on the landscape (Ogban *et al.*, 1999). The differences in properties of soil occupying different landscape position on a toposequence are caused by water and material movement and distribution along a slope. However, Moorman (1981) stated that the different landscape position influence runoff, drainage, erosion, dictates and thus soil genesis. The extent of runoff and erosion dictates the surface movement and distribution of basic cations. Soils especially in the tropics are formed in different section of the topography. The rate of soil formation vary along the various segment of the topography such as the crest, middle slope, lower slope and valley bottom as the result of deposition of materials in the various sections of the landform (Osodeke, 2017).

Fadama (wetland or floodplains) resources constitute an important agricultural ecology in the world and are major contributor of economic growth of the society (Nsor and Uhie, 2016). They also stated that the functions of fadama include water storage, nutrients transformation, growth of living organism including fishes and wetland crops. Brinson (1995) observed that location and size of a wetland may determine what functions it will perform. Wetland soils have great potential for sustainable increase in food production (crops and fisheries) because of their inherent fertility status and their occurrence in flat or near flat landscape where soil erosion is not a major constraint. Usor and Uhie, (2016) in their conclusion observed that the major challenges in wetlands are Fe- toxicity and noted that fadama are usually young soils due to few profile development.

Information for utilization of wetland for fish and rice farming in the study area is very scarce hence the study was conducted to find out the variation in soils physical and chemical properties along the toposequence.

Materials and Methods

Study Area

The study was conducted in Donga, along the Donga River which lies between 7°41'49.4" N and 10° 04' 13.5" E with 131 masl. The soils of Donga were formed from undifferentiated basement complex (shale and siltstone mix) according to FMWR (1991). The area is characterized by tropical climate with distinct wet and dry seasons. The relative humidity varies as the season (about 40 % in January and 90 % in July), The area has a tropical hot and wet weather with distinct rainy season (May – October) and dry season (November – April). Annual rainfall ranges from 1100 – 1250 mm. The mean annual temperature is about 29 °C indicating the tropical nature of the environment and characterization of the climate area as hot (temperature can reach 40 °C in March). The temperature of the area, although vary slightly annually and seasonally, remains high throughout the year and located in southern guinea savannah on Nigeria. It belongs to the guinea savannah agro-ecology with a sub-humid climate.

Soil sampling

Three mapping units were identified at equi-distance as crest, mid-slope and foot-slope using transect survey method. In each mapping units three profile pits were dug, soil samples were collected based on horizon differentiation for analysis of soil properties using standard procedures.

Laboratory analyses

Particle size distribution was determined by Bouyoucos hydrometer method (Gee and Or, 2002). Soil pH (H_2O) was determined electrometrically using glass electrode pH meter in a solid-liquid ratio of 1:2.5 (Hendershot *et al.*, 1993). Total nitrogen was determined by micro-Kjeldahl digestion technique method (Bremner, 1996). Exchangeable bases were determined by the neutral ammonium acetate procedure buffered at pH 7.0 (Thomas, 1982). Exchangeable acidity was determined by a method described by (McLean, 1982). Total carbon was analyzed by wet digestion (Nelson and Sommers, 1982). Available phosphorous was determined by Bray ll method according to the procedure of (Olsen and Sommers, 1982). Bulk density was determined by the core method (Grossman and Reinsch, 2002). Total porosity (P_o) was obtained from bulk density (ℓp) values with assumed particle density (ℓs) 2.65 g cm^{-3} as follows, Porosity (Po) =100 – (ℓp/ℓs) ×100/1.

Statistical Analyses

Variability among soil properties analyzed using Analysis of variance (ANOVA) and mean comparisms were made using the least significant difference (LSD) at $p<0.05$ levels (Wahua, 1999). Coefficient of variation as used and ranked according to Wilding *et al.* (1994) was used to estimate the degree of variability existing among soil properties of the studied soils.

Results and Discussion

The results (Table 1) indicated that sand fraction generally dominated the soils along the toposequence. The mean values for sand were 691.7 g kg^{-1}, 729.6 g kg^{-1} and 691.9 g kg^{-1} for crest, mid-slope and foot-slope, respectively as the mid-slope has the highest mean. Sand content had irregular pattern of decrease with soil depth at the crest and foot-slope pedon while at the mid-slope it increased. The high sand content could be associated with the parent material (Onweremadu *et al.,* 2011) and climatic condition that encourage the sorting of the soil particles. This finding conforms to the findings of Osujieke *et al.* (2016) in soils of southeastern Nigeria. Silt content in the horizon increased with depth in all the profiles. The removal of silt material from top horizon may be due to cumulization that is common in the study area. The mean values for silt were 130.8 g kg^{-1}, 109.5 g kg^{-1} and 84.1 g kg^{-1} for crest, mid-slope and foot-slope, respectively as the mid-slope has the highest mean. These results are in agreement with the findings of Ojeniyi and Ighomore (2004) in soils of southwest Nigeria. The clay content showed higher values in the topsoil horizon than the subsoil horizon, this may be due to enrichment supply by sediments. The mean value for clay was 204.5 g kg^{-1}, 160.9 g kg^{-1} and 224 g kg^{-1} for crest, mid-slope and foot-slope, respectively and the highest mean at foot-slope. The clay enrichment in Bt_2 horizons at crest and foot-slope resulted to argillation as a result of illuviation and eluviations process. This agreed with the works of Chikezie *et al.* (2009) and Malgwi *et al.* (2000). However, clay particles are of great value to fadama users because of its ability to retain or hold water. The clay content at the foot-slope resulted from the deposit of finer particle due to erosion runoff. This agreed with the findings of (Musa and Gisilanbe, 2017) that downward movement of clay particles as a result of the action of erosion, transportation and deposition down slope. Noma *et al.* (2011) also reported similar results. The SCR (Table 1) as observed from the study showed mean of < 1. This is an indication of reserved weatherable mineral in the substratum as evidenced by plinthic kandiusalfs according to USDA, (2015). The SCR is also in index for extent of weathering as noted by Olehge and Chokor, (2015).The textural class of the studied toposequence were dominated largely by sandy loam in the crest, sandy clay loam in the mid-slope and sandy clay in foot-slope where the impedance of water was encountered as well as stoneline which is an evidence of lithic discontinuity. The mean values of bulk density (Table 1) were 1.39 g cm^{-3}, 1.31 g cm^{-3} and 1.43 g cm^{-3} for crest, mid-slope and foot-slope, respectively, though the bulk density values are within the range for good rooting for crops (soil survey staff, 2006 and Landon, 1991). However, the surface horizons recorded high level of bulk density which may be due to activities of herds grazing frequently and this coupled with routinely use of the land for fadama rice cultivation in the study area. The result of the bulk density conforms to the findings of (Musa and Gisilanbe, 2017) on soils of northeast Nigeria but in concurrence to the findings of (Tekwa *et al.,* 2011). The total porosity values followed are relationship with the bulk density values (the inverse relationship that is the bulk density decreases as the porosity increases). The porosity values ranges from 36.98 % - 55.09 %. The electrical conductivity (EC) of the soil had range of 0.78 dS m^{-1} - 1.99 dS m^{-1} as 4 dS m^{-1} is critical level according to Landon, (1991). The EC level at the foot-slope could be attributed to the deposition saline particles due to runoff from the upper slope. The EC is an important soil parameter because when sodium is high in the soil, plants cannot absorb enough water from it due to osmotic pressure and desorption of water from the roots cells may occur. It also affects the soil aggregate stability making it unsuitable for crop growth and development (Waniyo *et al.*, 2015). EC increased with soil depth at the crest and foot-slope while it decreased at the mid-slope. The result (Table 1) showed that the soil physical properties were no significant among the pedons except the silt fraction and porosity. Silt fraction of the crest and mid-slope differed significantly that of the foot-slope while silt fraction had no significant difference between the crest and mid-slope. The difference among the silt content could be associated to shallow nature of the pedon at foot-slope. Porosity of the mid-slope differed significantly with that of crest and foot-slope which could be attributed to texture and bulk density level of the study sites. However, the non significant differences could be associated with similarity in parent material, climate and soil management practices of the study area.

Table 1: Soil physical properties of the studied pedons.

Horizon	Depth (cm)	Sand ⟶	Silt g/kg	⟵ Clay	SCR	TC	BD (g/cm^3)	Po	EC (dS/m)
				SUMMIT					
Ap	0-15	689.4	103.4	207.2	0.49	SL	1.67	36.98	1.32
AB	15-45	697.9	104.7	197.4	0.53	SL	1.19	55.09	1.99
Bt$_1$	45-70	769.7	115.5	114.8	1.01	SL	1.39	47.54	0.88
Bt$_2$	70-100	609.8	91.5	298.7	0.03	SCL	1.32	50.20	1.67
Mean		**691.7**	**103.8**	**204.5**	**0.52**		**1.39**	**47.45**	**1.27**
				MIDSLOPE					
Ap	0-15	679.2	101.9	218.9	0.47	SCL	1.52	44.00	0.98
AB	15-60	693.3	104.0	202.7	0.51	SCL	1.19	55.09	1.54
Bt$_1$	60-85	810.6	121.6	67.8	1.97	LS	1.32	50.20	1.11
Bt$_2$	85-110	735.4	110.3	154.3	0.72	SL	1.19	55.09	0.79
Mean		**729.6**	**109.5**	**160.9**	**0.92**		**1.31**	**51.1**	**1.11**
				FOOTSLOPE					
Ap	0-15	810.6	82.2	107.2	0.77	LS	1.67	36.98	1.45
Bt	15-40	573.2	86.0	340.8	0.25	SC	1.19	55.09	1.64
Mean		**691.9**	**84.1**	**224.0**	**0.51**		**1.43**	**46.04**	**1.55**
LSD$_{0.05}$		**175.6**	**17.84**	**186.5**	**1.13**		**1.34**	**2.79**	**0.77**

SCR= silt clay ratio, TC= textural class, BD= bulk density, EC= electrical conductivity, SL= sandy loam, SCL= sandy clay loam, LS= loamy sand, SC= sandy clay

TABLE 2: Soil chemical properties of the studied pedons

Horizon	Depth	$pH(H_2O)$	OC	TN	C/N	Av.P	Av.S	Ca	Mg	K	Na	TEA	ECEC	Ca:Mg
			g/kg			mg/kg				cmol/kg				
							SUMMIT							
Ap	0-15	5.52	9.3	1.10	8.45	8.32	1.11	3.40	6.60	1.26	2.31	1.23	23.06	0.52
AB	15-45	5.02	11.1	1.30	8.54	7.50	1.02	3.87	5.35	1.52	2.41	1.24	21.89	0.72
Bt_1	45-70	6.32	6.9	0.80	8.63	5.54	0.76	2.86	6.60	2.26	7.15	1.32	25.73	0.43
Bt_2	70-100	6.66	15.7	1.90	8.27	10.52	1.44	2.94	7.57	2.14	5.15	1.33	31.65	0.39
Mean		**5.88**	**10.75**	**1.28**	**8.47**	**7.97**	**1.08**	**3.27**	**6.53**	**1.79**	**4.26**	**1.28**	**25.58**	**0.52**
							MIDSLOPE							
Ap	0-15	5.13	7.3	0.90	8.11	6.17	0.84	3.19	7.35	1.26	1.70	1.2	20.87	0.43
AB	15-60	5.46	8.6	1.00	8.60	9.70	1.32	2.43	7.70	1.01	2.61	1.21	24.66	0.32
Bt_1	60-85	5.72	5.9	0.70	8.43	6.99	0.95	3.61	8.33	1.42	1.96	1.36	23.67	0.43
Bt_2	85-110	5.84	14.3	1.70	8.41	4.98	0.68	2.57	7.24	1.01	4.18	1.05	21.03	0.35
Mean		**5.54**	**9.03**	**1.08**	**8.39**	**6.96**	**0.95**	**2.95**	**7.66**	**1.18**	**2.61**	**1.21**	**22.56**	**0.38**
							FOOTSLOPE							
Ap	0-15	5.73	7.7	0.90	8.56	9.14	1.25	2.90	3.61	1.03	2.51	1.27	20.46	0.80
Bt	15-40	6.53	7.5	0.09	8.33	5.05	0.69	1.41	5.76	1.64	6.11	0.64	20.03	0.25
Mean		**6.13**	**7.6**	**0.49**	**8.45**	**7.10**	**0.97**	**2.15**	**4.68**	**1.33**	**4.13**	**0.69**	**20.25**	**0.53**
$LSD_{0.05}$		**1.17**	**7.02**	**0.96**	**0.36**	**4.46**	**0.61**	**1.27**	**1.82**	**0.77**	**3.99**	**0.39**	**6.37**	**0.41**

OC= organic carbon, TN= total nitrogen, Av.P= Available Phosphorus, Av.S = Available Sulphur, TEA= Total Exchangeable Acidity, ECEC= Effective Cation Exchange Capacity

The chemical properties (Table 2) indicated that the pH distributions were irregular and ranged from moderately to slightly acidic in all pedons according to the rating of Chude *et al.* (2011). The pH had mean of 5.88, 5.54 and 6.13 for crest, mid-slope and foot-slope, respectively. The acidic level at the upper slope may be attributed to washing away of basic cations down the slope. However, the pH is low compared with the level reported by (Jamala and Oke, 2013) in soils of northeast Nigeria. Soil organic carbon varied from low to moderate according to the rating of Landon (1991). Organic carbon ranged from 6.9-15.7 g kg^{-1} for crest, 5.9-14.3 g kg^{-1} for mid-slope and 7.5-7.7 g kg^{-1} for foot-slope. The Bt_2 horizon had higher OC over other horizons at the crest and mid-slope while at the foot-slope the Ap horizon had the highest. The OC level at the crest could be attributed the vegetal cover which give rise to organic material deposit. The OC content was higher when compared with the findings of (Musa and Gisilanbe, 2017) in soils of northeast Nigeria. Total nitrogen (Table 2) values according to Enwezor *et al.* (1990) were low with the mean of 1.28 g kg^{-1}, 1.07 g kg^{-1} and 0.49 g kg^{-1} for crest, mid-slope and foot-slope, respectively. The upper limits for total nitrogen was 2 g kg^{-1} above which eutrophication will set in resulting from high biological oxygen demand (BOD) as fadama always receive materials during seasonal flooding. The C/N is important for determining mineralization and immobilization of nitrogen, the C/N ranged from 8.11 - 8.63 which is below 25 favours mineralization set by Paul and Clark (1989). Available P (Table 2) increased down the profile in the mid-slope and decreased in crest and foot-slope with mean values of available P was 7.97, 6.96 and 7.10 mg kg^{-1}. The Available P was low (mid-slope) to moderate (crest and foot-slope) requiring P- fertilization as critical levels is 10 mg kg^{-1} - 16 mg kg^{-1} (Adeoye and Agboola, 1985). The result of the available P is low when compared to the findings of (Tekwa *et al.*, 2011) in soils of northeast Nigeria. The Ca levels were low to moderate (ranging from1.41 cmol kg^{-1}, 3.87 cmol/kg and foot-slope with lowest mean of 2.15 cmol kg^{-1}) while the critical level is 5 cmol kg^{-1}(Amalu, 1997). The Mg was generally higher than Ca levels in all the profiles and also dominates the effective cation exchange capacity of the soil. The sodium content of the soil were find to be very high with mean values of 4.26 cmol kg^{-1}, 2.61 cmol kg^{-1} and 4.14 cmol kg^{-1} for crest, mid-slope and foot-slope, respectively. The K mean values as obtained were 1.79 cmol kg^{-1}, 1.18 cmol kg^{-1} and 1.34 cmol kg^{-1} for crest, mid-slope and foot-slope, respectively. The K in the profile is adequate for crop utilization. Generally, ECEC of the soils were high being > 20 cmol kg^{-1} in all the soil studied. This may be as a result of the constant supply of sediments and high surface colloidal particulates (humus) as well as weatherable parent material which had encouraged intense addition of exchangeable cations in these soils. Sulphur is an important micronutrient in plant nutrition especially on many protein enzymes that regulate photosynthesis and nitrogen fixation (Brady and Weil, 2014). It was found to be low according to the ratings (< 3 mg kg^{-1}) of Landon, (1991). Available S recorded means of 1.08 mg kg^{-1}, 0.95 mg kg^{-1} and 0.97 mg kg^{-1} in crest, mid-slope and foot-slope, respectively. The surface horizon of the foot-slope had more available S when compared with the other surface horizons. Ca:Mg ratio of <5.1 indicates low activity clay (Brady and Weil, 2014). The Ca:Mg had mean of 0.35, 0.38 and 0.53 in crest, mid-slope and foot-slope, respectively. The soils are infertile when compared with the rating (< 3) of (Landon, 1991). Generally, the mean values found at the foot-slope may be as result of its moisture status as it holds more water than the other profiles along the toposequence. However, the soil chemical properties recorded non-significant difference among the studied pedons.

The Table 3 indicated the coefficient of variation of soil physical and chemical properties on each mapping unit along the toposequence. Sand fraction and bulk density recorded low variation ($\geq$8.1 % $\leq$14.56 %) at the crest and mid-slope while at the foot-slope it recorded moderate variation ($\geq$24.3 % $\leq$32.72 %). Soil pH showed low variation among the mapping units with the least in mid-slope (5.68 %). The result is in conformity with the findings of (Ndukwu *et al.*, 2012) that pH of most tropical soils indicates low variation due to parent material. However, soil pH is an important variable in soil; it regulates the biochemical functions in the soil (Brady and Weil, 2014). Organic carbon showed the various classes of variation in all the slopes, moderate variation (34.62 %) in crest, high variation (40.84 %) in mid-slope and low variation (1.86 %) in foot-slope. The variation could be associated with amount of organic material deposit and rate of decomposition. Total N had high variation in all the physiographic position ($\geq$36.44 % $\leq$115.71 %). The rate of variation could be related to rate of mineralization and volatilization due to high temperature. The rate of variation by available P could be related to P fixation and runoff. The SCR and clay ($\geq$42.18 % $\leq$77.76 %) fraction showed high variation in all the physiographic positions. The ECEC showed moderate variation in crest and low variation in the other physiographic positions. The C:N ratio had low variation ($\geq$1.81 % $\leq$3.43 %) in all the physiographic positions. The rate of variation recorded by total N and available P is similar to the findings of (Osujieke, 2017). Generally, soil properties recorded more high variation at the foot-slope compared to other physiographic positions which may be due to the toposequence.

TABLE 3: Variability of selected soil properties expressed in Coefficient of variation

	SUMMIT				MIDSLOPE				FOOTSLOPE			
Soil properties	**Mean**	**SD**	**CV(%)**	**Ranking**	**Mean**	**SD**	**CV(%)**	**Ranking**	**Mean**	**SD**	**CV(%)**	**Ranking**
pH(H_2O)	5.88	0.75	12.69	LV	5.54	0.32	5.68	LV	6.13	0.56	9.23	LV
OC (g/kg)	10.75	3.72	34.62	MV	9.03	3.69	40.84	HV	7.6	0.14	1.86	LV
TN (g/kg)	1.28	0.46	36.44	HV	1.07	0.43	40.46	HV	0.49	0.57	115.71	HV
Ca(cmol/kg)	3.27	0.47	14.29	LV	2.95	0.55	18.65	MV	2.15	1.05	48.89	HV
Av.P (mg/kg)	7.97	2.06	25.87	MV	6.96	2	28.8	MV	7.1	2.89	40.76	HV
Mg(cmol/kg)	6.53	0.91	13.93	LV	7.66	0.49	6.41	LV	4.68	1.52	32.45	MV
K (cmol/kg)	1.79	0.48	26.86	MV	1.18	0.2	17.14	MV	1.33	0.43	32.31	MV
C:N	8.47	0.15	1.81	LV	8.39	0.24	3.43	LV	8.45	0.16	1.93	LV
ECEC(cmol/kg)	25.58	4.35	17.01	MV	22.56	1.9	8.43	LV	20.25	0.3	1.5	LV
Ca:Mg	0.35	0.2	55.26	HV	0.38	0.06	14.69	LV	0.53	0.39	74.08	HV
Na	4.26	2.34	54.9	HV	2.61	1.11	42.6	MV	4.31	2.55	59.06	HV
SCR	0.52	0.4	77.76	HV	0.92	0.71	77.4	HV	0.51	0.37	72.1	HV
SAND (g/kg)	691.7	65.4	9.5	LV	729.6	59	8.1	LV	691.9	167.9	24.3	MV
SILT (g/kg)	103.8	9.83	9.46	LV	109.5	8.85	8.09	LV	84.69	2.69	3.2	LV
CLAY(g/kg)	204.5	75.2	36.8	HV	160.93	67.88	42.18	HV	224	165.2	73.7	HV
BD(g/cm^3	1.39	0.21	14.56	LV	1.71	0.16	11.95	LV	1.43	0.34	32.74	MV
TEA (cmol/kg)	1.28	0.05	4.08	LV	1.21	0.13	10.51	LV	0.96	0.45	46.65	HV
Po(%)	47.45	7.65	16.12	MV	51.09	2.26	10.3	LV	46.03	12.81	27.82	MV

SCR= silt clay ratio, TC= textural class, BD= bulk density, OC= organic carbon, TN= total nitrogen, Av.P= available Phosphorus, Av.S = available sulphur, TEA= total exchangeable acidity, ECEC= effective cation exchange capacity, SD= standard deviation, CV= coefficient of variation, < 15= low variability, ≥ 15≤35= moderate variability, > 35= high variability.

Conclusion

This study has shown the interactions between soil properties and how topographic units can influence the physical and chemical properties along a toposequence. The result obtained from laboratory analyses indicated that the investigated soils were dominated with sandy soil fractions. The textural class of the studied toposequence were dominated largely by sandy loam in the crest, sandy clay loam in the mid-slope and sandy clay in foot-slope where the impedance of water was encountered as well as stoneline which is an evidence of lithic discontinuity. The bulk density fell within the acceptable limit of < 1.85 g kg^{-1} for ease of root penetration. Soil pH was moderately or slightly acidic. Organic carbon and total nitrogen were low. ECEC of the soils were high being > 20 cmol kg^{-1} in all investigated soils this may be as a result of the flood plain sediment enrichment. Soil pH is the only chemical property that recorded low variability while most chemical properties were moderately and highly variable. Also, most physical properties had low variability except clay and silt which exhibited high variability. Therefore, controlled grazing is recommended to ameliorate topsoil compaction.

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