Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com

Characterization and Classification of Soil-Landform Features in Nigeria's Sokoto-Rima Floodplains

***Talha I. Z[1], S. S Noma[2], I.B Buji[1], N. M. Danmowa[2], Adamu I[1]**

[1*]Department of Soil Science, Faculty of Agriculture, University of Maiduguri, Nigeria

[2]Department of Soil Science and Agricultural Engineering, Usman Danfodiyo Universty Sokoto, Nigeria

ARTICLE INFO

Article history:
Received July 2nd, 2022
Received in revised form August 20th, 2022
Accepted August 24th, 2022
Available online August 25th, 2022

Keywords:

Soil
Landform position
Sokoto
Sokoto-Rima
Floodplains

Corresponding Author's E-mail Address:
zannaahtalha@gmail.com +2348032455460
https://doi.org/10.36265 njss.2022.320201
ISSN– Online **2736-1411**
Print **2736-142X**

ABSTRACT

The study was to identify and classify soils in floodplains along the Wamakko area of Sokoto-Rima in Nigeria. After profiling, samples taken from each horizon were identified, characterized, and classified into four soil types: pedons 1 and 4 (Vertisols) and pedons 2 and 3 (Entisols). The results indicate an ideal pH range for most agronomic crops on the surface and subsurface horizons (pH 6.2–6.9). The organic carbon content was too low in all the studied horizons. The surface soil (0.71 to 1.39 g/kg) was relatively higher than the subsurface (0.88 to 1.41 g/kg) soil horizons. The surface and subsurface soils were too low (0.043 to 0.120 g/kg) in total N and available P content (0.47 to 1.28 mg/kg) irrespective of slope positions. On a gently sloped (2–5%) gradient, the highest N (0.120 g/kg) and P (1.28 mg/kg) values were recorded. Calcium and magnesium were the dominant exchangeable bases in all slope positions. Surface (7.60 to 12.4 cmol (+)/kg) and subsurface (6.58 to 10 cmol (+)/kg) soils have medium cation exchange. The medium ranking of percent base saturation indicates the presence of basic cations in the exchange complex. On the surface horizons, they ranged from 49.03% in Pedon 4 to 65.25% in Pedon 1. On the subsurface soils, PBS ranged from 43.17% in the B horizon (Pedon 2) to 76.59% in the layer of the B horizon (Pedon 1). The nutrient content was higher in lower depositional areas. The interactions between soil and landforms become significant in agronomic management.

1.0 Introduction

Most floodplains are land areas close to rivers and streams, and formations are polyphasic making them prone to frequent flood disasters. The majority of the rural population along the floodplains of the Sokoto Rima, also known as Fadama land, has relied on agricultural operations as a source of income. The floodplains provide year-round moisture, suitable for dry-season cultivation, supporting the rain-fed agriculture of the farming community. The floodplain features are landforms produced by stream erosion, sediment transport, and deposition (Leopold et al., 2020). Therefore, the development of landforms collected with the materials serene illustrates the development and distribution of the soils along the Sokoto Rima floodplains. The flood-affected area often results in the degradation of the land along the Rima River in Sokoto, which is coming along with severe and pervasive issues that threaten agricultural development and food security in the country (Dell'Angelo et al., 2017). These have marked effects on agricultural production, thus affecting soil and the environment (Muktar et al., 2020) and extending up to the upland site (Bilskie and Hagen, 2018). Because of the ever-changing nature of the Fadama terrain, which is frequently fast-tracked by recurring flood catastrophes that produce in-stream erosion, sediment transport, and deposition, a holistic assessment of how development can influence or affect them is required (Otieno, 2004). Furthermore, this will allow us to obtain improved knowledge and information on floodplain natural resources, which can help distinguish between places that should be left alone, sites that can accommodate some uses but not others, and lands best suited for development (Hatimuria, 2020).

Understanding the soil and the environment involves soil characterization and classification, which are of great significance in the management and sustenance of the land (Dominati et al., 2010). Soil characterization and classification via physical, chemical, and mineralogical phenomena simplify our understanding and are a tremendous resource for humanity, especially for food security and environmental sustainability (Gomiero, 2016). We rely on soil quality to develop crops, manage forests and grasslands, and sustain ourselves (Lehmann et al., 2020). It is a fact that soil characteristics and landform position are significantly related, as it primarily focuses on the movement of soil and water (Zhu and Lin, 2011, Pain et al., 2016). A thorough soil assessment aimed at obtaining superior soil production and management emphasized the need for establishing such linkages that usually lead to the collation of different types of landforms and, consequently, different types of soils (Zinck 2013). As a result, a pedological study and classification of a specific area's soils is essential in determining the area's potential and constraints for enhanced and sustained agricultural production (Lelago and Buraka, 2019). Furthermore, soil classification allows soil scientists, policymakers, planners, researchers, and other professionals in related disciplines to make the most of their resources by estimating productivity and promoting technology transfer and knowledge sharing (Dinssa and Elias, 2021).

It becomes critical to conduct site-specific soil characterization to identify the existing heterogeneity of the soil system to generate appropriate information for determining soil potential and effective soil management strategies. Several studies on soil characterization in the vicinity of the study site do not aggregate landform and soil type, and none of these works addresses site-specific issues in the Gyrabshi towards Gidan Gajere-Wamakko Area of the Rima River in Sokoto, Nigeria. Therefore, we describe the morphological features of the soils, assess their physical and chemical characteristics from different landform positions, and classify them according to the taxonomic classification systems.

2.0 Materials and methods

2.1 Description of the study site

The study site is along the Sokoto-Rima floodplain of the Wamakko area of Sokoto State, situated between latitudes 13o041 and 13o061N and longitudes 5o 101 and 5o 121E. The River Rima, Nigeria's major perennial river in the northwest, drains it (Emeribe et al., 2019). The climate in the study region is tropical continental, with the majority of rain falling between June and September. Between October and May is the dry season. Rainfall is a term used to describe torrents of short-lived rain that fall at the start of the season and are generally accompanied by storms. The average annual rainfall is around 600mm, with most of it falling in July and August. The hottest temperature was 40° C (Wali et al., 2019). The quantity and duration of fadama surface flooding during the wet season is a critical component in floodplain cultivation. Irrigated farmland dominates the floodplains, but rain-fed agriculture is also common.

The research area's topography is largely Fadama lowland and a relatively flat high upland area (Hayatu et al., 2018). The lowland topography characterizes the Sokoto Plains, which is approximately 300 meters above sea level on average. Isolated hills and escarpments cut through the lowland in a few spots (Hamidu et al., 2016). The geology has different sedimentary strata deposited in various environments, from continental to marine. The Gundumi formation, which rests above the foundation complex rock, is the oldest, whereas the Gwandu formation is the youngest (Akinbiyi et al., 2019). Crystalline rocks from the Pre-Cretaceous era lie beneath the sedimentary strata of the Sokoto–Rima floodplains. Three primary fault trends (recent alluvium, Cretaceous, and Tertiary deposits) are prevalent in the basin (Kogbe, 1989). The research site has a complicated geomorphic history that dates back to the Jurassic period, when the Gondwana plain, the earliest known erosion surface, was formed (Sombroek and Zonneveld, 1971). Their natural vegetation is a thorny open hedge plant savannah (Zonneveld, 1999).

2.2 Field study, sampling and profile description

A semi-detailed (1: 25,000) soil survey was conducted at the research location to identify the numerous pedons for characterization and classification. An initial assessment began on the research site by taking note of the landforms and other prominent features. A survey baseline follows along the topographical axis. The soil boundaries were detected using soil colour, textural differentiation, soil structure, and physiographic position. Micro pits (0.5m x 0.25m) were dug at 250-meter intervals in a regular grid pattern, with transects pegged and augured at 0.15m to 0.3m depth at 50-meter intervals, followed by profile descriptions according to FAO (2006). A profile pit was dug and documented in each of the four soil units (Pedon 1, Pedon 2, Pedon 3, and Pedon 4), and then three (3) samples were taken from each horizon for laboratory analysis. Samples for bulk density were taken from the genetic horizons using core samplers.

2.3 Laboratory analysis of physical and chemical characteristics

Soil samples were collected, air-dried, crushed, and sieved at a size of 2 mm. Gravel content was determined by weighing particles larger than 2 mm. The less than 2 mm fraction was taken and used for all physicochemical analyses. Particle size distribution was determined by the hydrometer method (Bouyoucos, 1951). Bulk density determination by the use of the core sampler method. Undisturbed core samples were oven-dried to a constant weight at 105 °C and divided the oven-dry weight of the soil sample by its volume, where Db = bulk density, M = oven-dry mass of the soil sample, and V = volume of the core sampler.

In a 1:1 soil-to-water ratio, a glass electrode pH meter was utilized to determine the soil reaction. The soil organic carbon content was determined by the Walkey-Black method (Nelson and Sommers, 1982). The excess dichromate was titrated with 0.5 N ferrous sulfates, using ortho-phenanthroline as an indicator. The soil was oxidized earlier using a standard potassium dichromate solution and sulfuric acid, which provided the heat of the reaction. Total nitrogen was determined by the macro-Kjeldahl method as reviewed by Bremner (1965) after digesting the soil sample with sulphuric acid. Available P was determined by the Bray No.1 extraction method (Bray and Kurtz, 1945). Na and K were determined using the flame photometer, and Ca and Mg were determined using the Atomic Absorption Spectrometer (AAS) at appropriate wavelengths. The CEC of the soils was determined by saturating the soil with a neutral ammonium acetate solution and washing the excess with alcohol. The exchangeable bases were determined using the ammonium acetate extract from the CEC determination. The samples afterwards went through distillation and titration against standard hydrochloric acid. Base saturation was computed by dividing the summation of the exchangeable bases by the NH4OAC cation exchange capacity (CEC) of the soils.

2.4 Statistical analysis

The minimum and maximum values, as well as the standard deviation and coefficient of variation, were calculated using statistical methods for the data set's measured variables (CV).The relationships between the A and B horizons in the soil units were evaluated using Pearson correlation coefficients (SAS, 2008).

3.0 Results and discussion

The pedons were established based on the variability of soil characteristics. They are Pedon 1 to 4 (Table 1). The area surveyed is about 75 ha and is resolved into four soil mapping units.

Table 1 Distribution of the different soil units of the of the study site by land area

Pedon	Percentage (%)	Area (hectares)
1	18.90	14.20
2	40.33	30.25
3	15.87	11.90
4	24.87	18.65

At Pedon 1, a total area of 14.20 hectares was covered, accounting for 18.90% of the total area studied (2–5% slope gradient) at an elevation of more than 200 mm above sea level. Pedon 4 spans 18.65 ha, or 24.87% of the total area studied and is on a comparable slope position (2–5%) at an elevation of 248 meters above sea level. Pedon 2 covered roughly 30.25 hectares, or 40.33.3% of the total area, and was on near-level land with a slope of 0.5–1.0% at an elevation of 244 meters above sea level. Pedon 3 was on very gently sloping land with a slope of 1.0–2.0% at an elevation of 246m above sea level. It covered an area of about 11.90 ha, representing 15.87% of the total area.

3.1 Soil morphological characteristics

3.1.1 Soil colour

Pedons 1 and 4, with a slope gradient of 2–5%, occupy 44% of the surveyed area classified as Vertisols. In pedon 1, the soils were generally dark grey (5YR 4/1) on the surface, changing to a grey colour (5YR 6/1) on the subsurface horizon (Table 2). Very faint red (2.5YR 4/8) to faint red (2.5YR 5/8) mottles were observed on the surface to subsurface horizons, while pedon 4 exhibits similar colouration in the subsurface. The reddish colour implies aerated soil and iron oxidation. The differences in colour across pedons and within a pedon are owing to differences in iron oxide forms, parent material types, organic matter concentration, and drainage conditions (Abate et al., 2014, Schaetzl and Thompson, 2015). On slope gradient classes near level (0.5–1.0%), pedon 2 (Entisol) shows a yellowish-brown (10YR 5/4) on the surface that changes sporadically to a dark greyish brown (10YR 3/2) in the subsurface layers. The surface horizon had no mottles, but the subsurface horizons had a few very faint yellow (10YR 8/8) to weak yellow (10YR 7/8) mottles. Pedon 3, classified as Entisol in a very gently sloping position (1.0–2.0%), has a strong-brown hue (7.5YR 4/6) at the surface that changes to yellowish-brown (10YR 5/6), grey (5YR 6/1), and yellowish-brown (10YR 5/4) on the subsurface.

The B1 horizon that overlies the Ap horizon in Pedon 2 and 3 ratifies the underdevelopment of the soils. These soils have weakly expressed features that closely resemble the underlying residuum. As a result, a soil-forming process occurring on the study site has undergone a sequence of geomorphic events in the floodplain, leading to the development of soils along its landform.

Table 2 Selected morphological characteristics of the soils of the Sokoto-Rima floodplains

Pedon	Horizon	Depth (cm)	Colour (moist)	Mottling	Structure	Consistence (dry)	Other features	Boundary Distinctness/ Topography
1	Ap	0-30	5YR 4/1	2.5YR 4/8	sbk	m(efi)	Roots net/w	C, S
	B	30-50	5YR 6/1	2.5YR 4/8	abk	m(fi)	Roots net/w	C, S
	Bg	50-80	5YR 6/1	2.5YR 5/8	sbk	m(efi)	Roots net/w	-
2	Ap	0-30	10YR 5/4	None	sbk	m(fr)	Cha. & roots	C, S
	B1	30-102	2.5YR 4/6	10YR8/8	abk	m(fr)	None	C, S
	2B	102-125	5YR 4/1	10YR7/8	sbk	m(fr)	None	C, S
	C	125-141	5YR 6/6	10YR7/8	bk	m(fi)	None	C,W
	C1	141-200	10YR 3/2	10YR7/8	bk	m(fr)	None	-
3	Ap	0-55	7.5YR 4/6	None	sbk	m(fr)	Cha. & roots	C, S
	B1	55-110	10YR 5/6	10YR7/8	sbk	m(fr)	Cha. & roots	C, S
	Bt	110-162	5YR 6/1	10YR 6/6	abk	m(fr)	None	C, S
	C	162-200	10YR 5/4	10YR6/8	abk	m(fr)	None	-
4	Ap	0-55	5Y 6/1	7.5YR7/8	sbk	m(fi)	Cha. & roots	C, W
	B	55-144	5YR 6/1	10YR7/8	pl	m(fi)	Roots net/w	C, W
	C	147-200	5YR 6/6	5YR4/6	m	m(fi)	None	-

SymbolsTexture:- vf = very fine sand , fs = fine sand, ; Structure:- sbk = subangular blocky, abk = angular blocky, bk = blocky, pl = platy, m = massive Consistence:- m(fr) = friable, m(fi) = firm, m(efi) = slightly rigid. Other features: - net/w = net work, Cha. = channels. Boundary:- C= clear , W= Wavy, S = Smooth. FAO (2006). Guidelines for soil description

3.1.2 Structure and consistency

In pedon 1, the soil structure was sub-angular and blocky, with a slightly rigid consistency (moist) in both the surface and subsurface horizons. In all of the horizons in this pedon, boundaries were clear with a few medium-sized root networks. The structure soils in Pedon 4 were sub-angular, blocky on the surface and massive in the subsurface horizons, with a consistency (moist) firm in all the horizons. There were few networks of roots on the surface and subsurface horizons. The boundary was wavy on all the horizons. Pedons 2 and 3 showed a sub-angular blocky structure on the surface and were blocky in the subsurface horizons, which were weak in development. The consistency (moist) is generally friable. There were channels and a few root networks on the surface horizon. On the surface, the boundary was clear, but it became wavy on the subsurface horizon. The soils were formed over extended periods from alluvial deposits and were underlain by weathered minerals.

3.1.3 Horizon boundaries and soil depth

According to Ditzler et al. 2017, all of the pedons were very deep (> 150 cm), except Pedon 1, which was moderately deep in soil depth class classification (50 to 100 cm). The rooting depth of the soil determines the quantities of plant nutrients and water available to the plant roots. Plant root growth, nutrient, and water availability were not affected by the depth of the pedon at the research site. The horizons of all pedons showed clear distinctness and smooth topography at the surface across all identified pedons except for pedon 4 (Vertisols), which had clear distinctness and wavy topography on both the surface and subsurface horizons. At Pedon 2, classified as Entisols, there was a change from clear distinctness and smooth topography to clear distinctness and wavy topography from 141 cm to 200 cm (Table 2). The variations in horizon boundaries on the surface and the subsurface horizons of the soil under study often reflect distinct morphological features at pedon depth, which signifies the early stages of soil development in the study site, as earlier reported by Ukut et al. (2014).

3.2 Soil physical characteristics

3.2.1 Soil particle size distribution

According to the Soil Science Division Staff (2017) rating, Pedon 1 (Vertisols, 2–5% slope gradient) was clay in texture at the surface and subsurface horizon. It has more than 40% clay, 45% sand, and 40% silt. The transition to silt clay loam in the B horizon was due to the downward migration of clay particles to the subsurface. The clay loam texture in pedon 4 (Vertisols) on a 2–5% slope position was in a regular pattern in both the surface and subsurface horizons (less than 40% clay and between 20 to 45% sand). At Pedon 2 (0.5–1.0% slope), the soil textural class is sandy loam on the surface horizon, changing irregularly to clay loam on the subsurface horizon. The texture of the soils in pedon 3 (1.0–2.0%) is sandy loam on the surface horizon, changing intermittently to loamy sand on the subsurface horizon. The surface horizon of Pedon 2 and 3 (Entisols) had a sandy loam texture (7 to less than 20% clay and more than 52% sand, and the percentage of silt plus twice the percent of clay is 30). The lack of a defined trend in soil texture along the topographic position could be due to erosion and accumulation influencing pedogenic processes, whilst the irregular inclination with depth could be related to differences in parent material weathering, similar to the findings of Tufa et al., 2021. Most subsoil horizons were formed by illuviation of clay minerals from the upper horizons, as evidenced by the rising clay content with depth of profiles in pedon 1 (Vertisols) and 2 (Entisols). Weathering, degradation of primary minerals, and addition may have resulted in the presence of clay minerals (Dinssa and Elias, 2021). The mineral structure of clay and its alterations resulting from weathering processes are variables in soil fertility and water retention capacity assessment (Ghonamey et al., 2020; Dinssa and Elias, 2021). The correlation matrix in the soil physical characteristics (Table 2) between the A and B horizons showed no significant relationships in the sand and clay contents; they correlate positively. The silt content on the surface and the surface horizons correlate negatively.

3.2.2 Silt/clay ratio

The silt clay ratio ranged from 0.82 to 0.53 (Pedon 1), 5.37 to 1.28 (Pedon 2), 0.75 to 1.16 (Pedon 3), and 2.67 to 1.07 (Pedon 4) on the surface and subsurface horizons. There was no consistent decrease or increase in clay/silt ratio with soil types and depth in the pedons 1–4 (Vertisols, Entisols, Entisols, and Vertisols). The FAO (1990) defined a low amount of weathering as a silt-to-clay ratio of less than 0.20. The silt clay ratio of old parent materials is less than 0.15, whereas the silt clay ratio of new parent materials is more than 0.15 (Van Wambeke, 1962). Results show that all the soils have silt/clay ratio above 0.15 or less than 0.20. It explains the low degrees of weathering in all of the pedons in the research area, which means that the materials are still young and have a high potential for weathering.

3.2.3 Bulk density

Except in Pedon 4, where there was a slight drop in the subsurface horizon, the bulk density increases unevenly with depth in all the pedons (Table 3). As previously noted by Dinssa and Elias, 2021, the increased bulk densities with soil depth could be due to the mass of the covered soil, poor porosity, and the significantly smaller amount of OM in the lower surface soil horizon. Surface horizon bulk density ranged from 1.31 to 1.34 Mg/m3 in this study, with Pedon 4 having the lowest density and Pedon 2 and 3 having the highest. According to Hazelton and Murphy (2016), the bulk density of the examined soils was low. The optimal bulk density ranged between 1.3 and 1.6 Mg/m3. The low bulk densities from the findings had no effect on root development and penetration, aeration, or nutrient and water transport, making them ideal for crop production (Reichert et al., 2009). As defined by Wilding (1985) and Akinbola (et al., 2006), bulk density variability was minimal (0–15%).

3.2.4 Particle density

Mineral soils have an average particle density of 2.65 Mg/m3 (Brady and Weil 2008). The particle density of the studied soils (Pedon 1 to 4) was less than 2.65 Mg/m3 on average (Table 3). According to Weil and Brady (2017), particle density increased with the depth of soil horizons similar to the examined soils. The particle density of soils increases as they become coarser. Their building blocks (minerals) and composition might be responsible for the low particle density values. On the surface and in the subsurface, particle density variability was the least variable (0–15%).

Table 3 Selected physical characteristics of the soils of Sokoto-Rima floodplains

Depth (cm)	Horizon	Sand (%)	Silt (%)	Clay (%)	Textural class	Silt/clay ratio	Bulk density --(Mg/m^3)	Particle density -(Mg/m^3)	Porosity (%)
Pedon 1									
0-30	Ap	18	37	45	Clay	0.82	1.33	2.52	50
30-50	B	20	43	39	Silt Clay Loam	1.10	1.29	2.57	50
50-80	Bg	16	29	55	Clay	0.53	1.65	2.54	37
Mean value		18	36	46		0.82	1.42	2.54	46
CV (%)		10	19	19		34	13.4	1.18	16
Pedon 2									
0-30	Ap	49	43	8	Sandy Loam	5.37	1.34	2.40	47
30-102	B1	51	35	14	Sandy Loam	2.50	1.31	2.47	48
102-125	2B	58	34	8	Sandy Loam	4.25	1.58	2.49	49
125-141	C	35	36	29	Clay Loam	1.24	1.44	2.38	45
141-200	C1	84	9.2	7	Sandy Loam	1.28	1.56	2.58	40
Mean value		56	31	13		2.93	1.45	2.47	45
CV (%)		33	41	72		63	8.28	3.24	7.9
Pedon 3									
0-55	Ap	34	48	18	Sandy Loam	2.67	1.34	2.47	48
55-110	B1	54	39	7	Sandy Loam	5.57	1.38	3.24	45
110-162	Bt	35	51	14	Silt Loam	3.64	1.28	2.30	53
162-200	C	73	14	13	Loamy Sand	1.07	1.48	2.37	47
Mean value		49	38	13		3.23	1.37	2.31	48
CV (%)		38	44	34		57	5.84	2.59	7.1
Pedon 4								2.39	
0-55	Ap	37	29	34	Clay Loam	0.75	1.31	5.86	49
55-147	B	24	43	34	Clay Loam	1.07	1.31	2.55	50
147-200	C	35	35	30	Clay Loam	1.16	1.29	2.61	51
Mean value		33	36	33		0.99	1.30	2.61	50
CV (%)		23	20	7		21	0.77	2.59	2.0

CV = Coefficient of variability, where < 15% = least variable; 15-35% =moderately variable; >35% = highly variable.

3.2.5 Porosity

In contrast to bulk and particle densities, the total porosity decreased along the horizons of all soil pedons in the study site. The total porosity of the studied soils in the Sokoto rima floodplains ranged from 49% to 50% of the surface and 37% to 51% of the subsurface soil horizons (Table 3). FAO (2006) defined soil porosity of > 40% as very high, while most agricultural soils have a porosity of around 50%, allowing for limitless water and airflow as well as unrestricted root development (Rogers, 2015). The results show that the porosity values of the studied pedons on the surface horizons are within the range for crop production. Variability in porosity was medium in pedon 1, whereas all the other studied pedons were the least according to the ranking. Several studies have shown that soil quality differs across farm fields, causing crop yields to vary spatially (Franzen et al., 2018; Ahmad and Dar, 2020). There was a positive correlation between bulk density and porosity, with no significant relationships. Due to geology and pedologic soil-forming processes, spatial diversity in soil physical features exists within or among agricultural fields. Tillage and other management measures may influence soil variability (Bogunovic et al., 2018).

3.3 Soil chemical characteristics

3.3.1 Soil reaction (pH)

Except for pedon 3, the pH (H2O) of all the soils investigated declined somewhat with increasing depth. On both the surface and subsurface horizons, the pH values of all the analysed soils were less than seven and over six. The pH of the surface horizons ranges from 6.5 to 6.8. (Table 4). Weil and Brady's (2017) soil pH scoring curve suggests an optimum between pH 6 and 7, which is consistent with the production of most agronomic crops. The pH values were consistently the least variable (CV = 0–15%) in all the soil, irrespective of slope position.

3.3..2 Organic carbon

Pedon 1 (Vertisols) has a B horizon with total carbon values decreasing from 1.39 to 0.93 g/kg in the Bg horizon. On related slope position, Pedon 4 (Vertisols) decreased from 0.74 in the B horizon to 0.71 g/kg in the C horizon. Pedon 2 (Entisols) had decreased organic carbon content from B1 to 2B and C to C1 (Table 4). At a relatively gently sloped site (Pedon 3), organic carbon content is lower from 1.15 in B1 to 0.96 g/kg in Bt to 1.09 g/kg in the C horizon. The increasing quantities of litter on the surface caused total carbon levels to drop in all slope positions and profiles. Total carbon values generally decreased in all slope positions on the surface and the subsurface and were attributed to the higher amount of litter on the surface. Total carbon values generally decreased in all slope positions on the surface and the subsurface and were attributed to the higher amount of litter on the surface. The increasing quantities of litter on the surface caused total carbon levels to drop in all slope positions and profiles. The low levels in all slope positions may have accounted for the poor growth of crops and natural vegetation in the study area, the rapid turnover rates of organic materials with the high soil temperatures and organisms, and the low soil clay content as reported by Bationo et al. (2006). The organic carbon content of the soil was too (extremely) low as per the rating scale of Hazelton and Murphy (2016) in all the studied horizons. The organic carbon content of the surface soil horizons (ranging from 0.71 to 1.39 g/kg) was relatively higher than the subsurface (ranging from 0.88 to 1.41 g/kg) soil horizons.

According to the study by Dinssa and Elias (2021), the decreasing tendency as soil depth increases for all pedons (Table 4) indicates a substantially higher addition of decomposable organic materials on the surface than on the

Table 4 Selected chemical characteristics of the soils of Sokoto-rima floodplains

Depth (cm)	Horizon	pH (H_2O)	OC g/kg	TN g/kg	AP mg/kg	Exchangeable Bases cmol (+)/kg				CEC cmol (+)/kg	BS %
						Ca	Mg	Na	K		
Pedon 1											
0-30	Ap	6.6	1.41	0.120	0.55	2.40	1.30	1.09	1.10	9.02	65.29
30-50	B	6.6	1.39	0.120	0.53	1.80	1.10	1.04	1.10	6.58	76.59
50-80	Bg	6.4	0.93	0.059	0.47	1.60	0.80	1.17	1.00	7.10	64.36
Mean value		6.5	1.24	0.099	0.52	1.93	1.06	1.10	1.07	7.57	68.75
CV (%)			21.8	40.40	7.69	21.8	23.6	6.36	5.61	17.0	9.91
Pedon 2											
0-30	Ap	6.8	1.38	0.074	1.07	2.35	1.50	1.40	0.60	11.0	53.18
30-102	B1	6.6	1.19	0.069	0.69	1.20	1.05	1.25	0.70	9.73	43.17
102-125	2B	6.5	1.15	0.072	0.64	1.70	0.90	0.80	1.90	10.0	52.48
125-141	C	6.6	1.23	0.110	0.64	2.30	1.40	1.10	1.20	8.80	68.18
141-200	C1	6.2	1.15	0.065	0.59	2.40	1.80	0.70	1.10	7.90	75.94
Mean value		6.4	1.22	0.078	0.61	1.99	1.33	1.05	1.10	9.49	58.59
CV (%)		3.4	7.38	25.64	31.15	26.1	27.1	27.6	46.4	12.4	22.53
Pedon 3											
0-55	Ap	6.5	1.17	0.086	1.09	1.94	0.94	0.76	0.54	7.60	55.00
55-110	B1	6.9	1.15	0.091	0.68	1.80	0.80	0.52	0.30	6.90	49.57
110-162	Bt	6.6	0.96	0.050	0.62	1.80	1.30	0.90	1.00	7.03	71.12
162-200	C	6.3	1.09	0.065	0.49	1.30	0.90	0.40	0.50	6.89	44.99
Mean value		6.6	1.09	0.073	0.72	1.71	0.99	0.52	0.59	7.11	55.17
CV (%)		3.8	8.26	27.39	36.1	23.9	21.2	42.3	49.2	4.64	20.65
Pedon 4											
0-55	Ap	6.7	0.88	0.095	1.28	1.50	1.00	3.30	0.28	12.4	49.03
55-147	B	6.7	0.74	0.063	1.24	0.60	0.30	2.60	0.49	8.50	46.94
147-200	C	6.5	0.71	0.043	1.08	0.38	0.55	2.00	0.41	5.40	61.85
Mean value		6.6	0.78	0.067	1.20	0.83	0.62	2.63	0.39	8.77	52.61
CV (%)		1.7	11.5	44.70	9.17	19.7	56.4	24.7	28.2	39.9	15.30

CV = Coefficient of variability, where < 15% = least variable; 15-35% =moderately variable; >35% = highly variable.

subsurface horizons or a high amount of litter on the surface. The low quantities of organic carbon found could be due to seasonal floods in the area, which cause anaerobic conditions that prevent the total decomposition of organic waste, resulting in low crop and natural vegetation development in the research area. The coefficient of variation of organic carbon was generally low.

3.3.3 Total nitrogen

According to the rating scales developed by Bruce and Rayment (1982) and Esu (1991), nitrogen levels in the soils studied were low in content. The quantity of total nitrogen on the surface horizon was higher than the subsurface horizon. These trends are similar to those of the organic carbon content of the study site, implying that there is a strong relationship between total nitrogen and soil organic carbon. Weil and Brady (2017) state that losses by denitrification may be very high in the floodplains as the soils are commonly subject to alternate periods of wetting and drying. Furthermore, the low N contents obtained in the fadama soils may be due to the preponderance of low activity clays and the low organic matter contents of the soils. The low levels are irrespective of slope positions, but then the clay-rich Vertisols (Pedon 1) on a gently sloped (2–5%) gradient have recorded the highest value of 0.120 g/kg. Nitrogen is the most limiting plant nutrient in tropical soils (Brady and Weil, 2008). Total nitrogen variability was high in pedons 1 and 4, while pedons 2 and 3 were moderate.

3.3.4 *Available phosphorus*

Available phosphorus results reveal a consistent trend across all soil units, with greater levels on the surface horizons than on the deeper layers (Table 4). The highest value was in Pedon 4 on a 2.5% slope gradient (1.28 mg/kg), followed by Pedon 3 (1.09 mg/kg) and Pedon 2 (1.07 mg/kg), while the least was recorded in Pedon 1 (0.55 mg/kg). According to the Esu rating system, the soils have low available phosphorus. There was a diminishing trend of available P across the soil depth for all soil profiles. The source rock's low phosphate potential may have influenced the low phosphate levels found, similar to those reported by Landon (1991). In addition to low intrinsic phosphorus, another reason could be the decreasing soil organic matter content in all the pedon studied and their clay mineralogy, as was the case by Dinssa and Elias (2021). Available P was ranked the least variable in pedons 1 and 4 (Vertisols), while pedon 2 was moderate and pedon 3 was highly variable. That means available phosphorus management decisions should be spelt out for individual pedons under study.

3.3.5 Exchangeable bases

The quantities of calcium Ca^{2+} decreased consistently with the depth of the soil pedons (Table 4). Exchangeable Ca ranked highest on the exchange site. The mean values for the exchangeable calcium of the soils were 0.83 to 1.93 cmol (+)/kg. Metson, 1961, and Esu, 1991, rated the exchangeable calcium in the flood plains in the low range. Calcium was the dominant cation in the exchange site in all the soils. The preponderance of calcium shows the affinity of calcium over other cations at exchange sites. Exchangeable Mg ranked next to Ca on the exchangeable site. Mg values were generally in the medium range. The mean values of exchangeable Mg of the flood plain soils ranged from 0.33 to 1.33 cmol (+)/kg. The medium magnesium content might be due to inherent magnesium-bearing parent material, as Abate et al. (2014) suggested. Reports have shown that pH (H2O) values of 5 to 9 are optimum for calcium and magnesium availability (Hazelton and Murphy, 2016).

Calcium and magnesium were the dominant exchangeable bases in all slope positions, but Pedon 1 (Vertisols) on the gentle slope gradient class recorded the highest Ca value of 2.40 cmol (+)/kg and Pedon 2 (Entisols) on a near-level slope gradient class recorded the highest Mg value of 1.50 cmol (+)/kg. In all the pedons' surface and subsurface horizons, the exchangeable K content varied from medium to high, and the subsurface values were not consistent with depth. According to the ranking, exchangeable K is not the limiting ingredient for agronomic activities. The exchangeable Na has shown a similar trend to the exchangeable K throughout the studied profiles of the soils. The domination of Ca and Mg on the floodplains agrees with those made in the past for West African savannah soils in general (Kowal and Knabe, 1972); Uzu et al., 2003 for floodplains of north-western Nigeria, specifically the floodplains of Sokoto-Rima. Mg was generally medium in variability. Variability in K was least in pedons 1 and 2, which were moderate, whereas pedons 2 and 3 were highly variable. The spatial distribution of Ca and Mg calls for a unique management strategy.

3.3.6 Cation exchange capacity (CEC)

Table 4 shows that the overall cation exchange capacity (CEC) is "medium." The CEC varies between 7.60 (pedon 1) and 12.4 cmol (+)/kg (pedon 4) in the surface horizons. CEC values show a variation (decrease) with depth in all pedons under study. In the subsoil horizons, CEC varies between 6.58 (pedon 1) and 10 (pedon 2) cmol (+)/kg. The medium CEC values indicate that kaolinite is the dominant clay fraction of the soil, in agreement with Hamdan et al. (1998). The CEC values obtained in different slope positions correlate with the soil organic carbon and clay content (Tables 2 and 3). CEC values are higher in areas with a high organic carbon concentration, and clay fragments range from 8% to 45% on the surface horizons to 8% to 55% on the subsurface horizons (Tables 1 and 2). According to Brady and Weil (2008) and Weil and Brady (2017), the soil's organic carbon content significantly impacts its CEC. The higher CEC values found on the surface of all examined pedons correlate with more organic carbon content obtained and the decreasing organic carbon content in the subsurface, as reflected in the decreasing CEC. For soils in the floodplains of north-western Nigeria, Uzu et al. (2003) discovered that organic carbon content fell throughout the profile, accompanied by a decrease in CEC. CEC values were least variable in pedons 2 and 3 and medium in pedon 1, with a high CV value in pedon 4. As a result, assuming that soils within farmland have uniform properties may be deceptive. In a landscape, there is natural variation, which is often made complex by additional impositions by man through various forms of use or/and management practices (Adigun, 2008). These have implications for crop production since soil variability will lead to variability in crop performance and yield according to the ranking of Wilding, 1985, and Akinbola et al. (2006). The correlation matrix in the soil chemical characteristics shows no significant relationships in the soil pH, available phosphorus, Ca, K, and CEC between the A and B horizons and was negatively correlated. The organic carbon content correlates positively with significant relationships. There was a positive correlation between Mg, Na, and base saturation.

3.3.7 Base saturation (BS)

The percent base saturation varied over the soil depth for all pedons studied (Table 4). Percent base saturation on the surface soil horizons ranged from 49.03% in Pedon 4 (Vertisols) to 65.25% in Pedon 1 (Entisols). In the subsurface soils, PBS ranged from 43.17% in the B horizon (Entisols, Pedon 2) to 76.59% in the layer of the B horizon (Vertisols, Pedon 1). In all of the soil units studied, the percent base saturation was rated medium, and there was a reflection of the presence of the basic cations in the exchange site. The medium readings suggest that the soils have a moderate ability to supply plant nutrients, emphasizing the importance of proper soil management. The variance in PBS indicated the degree of leaching, which is a diagnostic soil characteristic for classification and the presence of depositional alluvial materials and weathering conditions. The Middle Cretaceous may have experienced the lengthiest period of soil instability. The subsidence likely stopped after the deposition, and a general uplift followed in the late Cretaceous period (Kogbe, 1989).

4.0 Conclusions

These findings confirm the redistribution of deposits from erodible to depositional sites in the floodplains (Fadama). Depositional sites have higher organic carbon and total nitrogen concentrations than erodible sites. The findings of this study approve the need to include the topographic characteristics of an agricultural field and their interactions with management when planning for soil nutrients.

References

Abate, N., Kibret, K., Gebrekidan, H., & Esayas, A. (2014). Characterization and classification of soils along the toposequence at the Wadla Delanta Massif, north central highlands of Ethiopia. *Journal of Ecology and the Natural Environment*, *6*(9), 304-320.

Adigun, M. O., Akinbola, G. E., Olaleye, A. O., & Obuh, J. (2008). Variability of soil properties across planted fallows under earthworm casts on an alfisols in South Western Nigeria. *World Journal of Agricultural Sciences*, *4*(4), 435-441.

Ahmad, S. F., & Dar, A. H. (2020). Precision Farming for Resource Use Efficiency. In *Resources Use Efficiency in Agriculture* (pp. 109-135). Springer, Singapore.

Akinbiyi, O. A., Oladunjoye, M. A., Sanuade, O. A., & Oyedeji, O. (2019). Geophysical characterization and hydraulic properties of unconsolidated floodplain aquifer system in Wamako area, Sokoto State, northwestern Nigeria. *Applied Water Science*, *9*(8), 1-10.

Akinbola, G. E., Ojetade, J. O., & Olaleye, A. O. (2006). Variability of soil properties along two toposequences on basement complex in South Western Nigeria. *Discovery and Innovation*, *18*, 44-52.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., & Kimetu, J. (2006). Soil organic carbon dynamics, functions and management in West African agro-ecosystems.

Bilskie, M. V., & Hagen, S. C. (2018). Defining flood zone transitions in low-gradient coastal regions. *Geophysical Research Letters*, *45*(6), 2761-2770.

Bogunovic, I., Pereira, P., Kisic, I., Sajko, K., & Sraka, M. (2018). Tillage management impacts on soil compaction, erosion and crop yield in Stagnosols (Croatia). *Catena*, *160*, 376-384.

Bouyoucos, G. J. (1951). A recalibration of the hydrometer for making mechanical analysis of soil. *Agronomy Journal 43: 434-438.*

Brady, N. C., & Weil, R. R. (2008). *The nature and properties of soils* (No. BOOK). Pearson Education, Inc..

Bray, R.H.and L.T. Kurtz (1945). Determination of total organic and available forms of phosphorus in soils. *Journal of Soil Science* 59: 39-45.

Bremmar, J. (1965) Total nitrogen, In: C. A. Black (ed). Methods of soil analysis. Agronomy No. 9. *America Society of Agronomy, Madison, Winsconsin*. USA.

Bruce, R. C., & Rayment, G. E. (1982). *Analytical methods and interpretations used by the Agricultural Chemistry Branch for soil and land use surveys.* Queensland Department of Primary Industries.

Dell'Angelo, J., D'Odorico, P., & Rulli, M. C. (2017). Threats to sustainable development posed by land and water grabbing. *Current Opinion in Environmental Sustainability*, *26*, 120-128.

Dinssa, B., & Elias, E. (2021). Characterization and classification of soils of Bako Tibe District, West Shewa, Ethiopia. *Heliyon*, *7*(11), e08279.

Ditzler, C., Scheffe, K., & Monger, H. C. (2017). Soil Survey Manual: Soil Science Division Staff. *Government Printing Office: Washington, DC, USA*.

Dominati, E., Patterson, M., & Mackay, A. (2010). A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological Economics*, *69*, 1858-1868.

Emeribe, C. N., Ogbomida, E. T., & Enoma-Calus, J. O. (2019). Climatic variability and estimation of supplementary irrigation water needs of selected food crops in the Sokoto-Rima River Basin, Nigeria. *Nigerian Journal of Environmental Sciences and Technology*, *10*, 86-104.

Esu, I.E. (1991). Detailed Soil Survey of NIHORT Farm at Bunkure, Kano State, Nigeria. Institute for Agricultural Research, Ahmadu Bello University, Zaria.

FAO (Food and Agricultural Organization) (1990). Soil Map of the World. Revised Legend, World Soil Resources Report, FAO Rome

FAO (Food and Agriculture Organization of the United Nations). (2006). Guidelines for soil description.

Franzen, D. W., Shannon, D. K., Clay, D. E., & Kitchen, N. (2018). Soil variability and fertility management. *Precision agriculture basics*, (precisionagbasics), 79-92.

Ghonamey, E., Kotb, Y., Abdellatif, A. D., & Abdel Ghaffar, M. K. (2020). Soil Mineralogy of North Western Desert, Egypt. *Egyptian Journal of Soil Science*, *60* (4), 485-500.

Gomiero, T. (2016). Soil degradation, land scarcity and food security: Reviewing a complex challenge. *Sustainability*, *8*(3), 281.

Hamdan, J., Burnham, C.P. and Ruhana, B. (1998). Physicochemical characteristics of exposed saprolites and their suitability for oil palm cultivation. *Pertanika Journal* 21:99-111.

Hamidu, H., Garba, M. L., Abubakar, Y. I., Muhammad, U., & Mohammed, D. (2016). Groundwater resource appraisals of Bodinga and environs, Sokoto Basin northwestern Nigeria. *Nigerian Journal of Basic and Applied Sciences*, *24*(2), 92-101.

Hatimuria, M. K. (2020). Chapter-8 Zooplankton Diversity of a Tropical Floodplain Lake (Beel) of Majuli River Island, Assam, Northeast India. *Applied Entomology and Zoology*, 113.

Hayatu, N. G., Sale, A., Abdullahi, I. L., Damabi, C. S., Buji, I., Sharu, M. B., ... & Nabayi, A. (2018). Effect of land utilization types on some physical and hydraulic properties of soils in Gidan Sule, Wamakko, Sokoto State, Nigeria. *International Journal of Research and Innovation in Applied Science*, *3*(11), 14-18.

Hazelton, P., & Murphy, B. (2016). *Interpreting soil test results: What do all the numbers mean?*. CSIRO publishing.

Kogbe, C.A. (1989). Cretaceous and Tertiary of the Iullemeden Basin in Nigeria. In: *C. A. Kogbe (eds) Geology of Nigeria, 377-421.* Jos, Rock View Publ.Co.

Kowal, J. M., Knabe, D. T., & Hydrological Technical Committee. (1972). An agroclimatological atlas of the northern states of Nigeria, with explanatory notes.

Lehmann, J., Bossio, D. A., Kögel-Knabner, I., & Rillig, M. C. (2020). The concept and future prospects of soil health. *Nature Reviews Earth & Environment*, *1*(10), 544-553.

Lelago, A., & Buraka, T. (2019). Determination of physico -chemical properties and agricultural potentials of soils in Tembaro District, KembataTembaro Zone, Southern Ethiopia. *Eurasian Journal of Soil Science*, *8*(2), 118-130.

Leopold, L. B., Wolman, M. G., Miller, J. P., Wohl, E., & Wohl, E. E. (2020). *Fluvial processes in geomorphology*. Courier Dover Publications.

Metson, A. J. (1961). *Methods of chemical analysis for soil survey samples* (No. 631.42 M48).

Muktar, A., Yelwa, S. A., Bello, M. T., & Elekwachi, W. Geospatial Analysis of Farmland Affected by 2020 Flooding of River Rima, Northwestern Nigeria.

Nelson, D.W. and E. Sommers (1982). Total C, organic matter. In A.L., page, R.H. Miller and D. R.. keeney (eds). *Methods of Soil Analysis.* Part 2. Chemical and Microbiological Properties. 2nd ed. Agronomy 9:539-579.

Otieno, J. A. (2004). Scenario study for Flood Hazard Assessment in the lower Bicol Floodplain Philippine using A 2D Flood model. ITC.

Pain, C. F., Abdelfattah, M. A., Shahid, S. A., & Ditzler, C. (2016). Soil-Landform Relationships in the Arid Northern United Arab Emirates. In *Geopedology* (pp. 211-225). Springer, Cham.

Reichert, J. M., Suzuki, L. E. A. S., Reinert, D. J., Horn, R., & Håkansson, I. (2009). Reference bulk density and critical degree-of-compactness for no-till crop production in subtropical highly weathered soils. *Soil and Tillage Research*, *102*(2), 242-254.

Rogers, D. H., Aguilar, J., Kisekka, I., Barnes, P. L., & Lamm, F. R. (2015). Agricultural crop water use.

SAS, S., Guide, S.U.S.: Version 9.4. Cary, NC, USA: SAS Institute Inc, 2008.

Schaetzl, R. J., & Thompson, M. L. (2015). *Soils*. Cambridge university press. Schaetzl, R. J., & Thompson, M. L. (2015). *Soils*. Cambridge university press.

Soil Science Division Staff. (2017). Soil survey manual. *USDA handbook 18*, 120-131.

Sombroek, W. G., & Zonneveld, I. S. (1971). *Ancient dune fields and fluviatile deposits in the Rima-Sokoto river basin (NW Nigeria): geomorphologic phenomena in relation to Quaternary changes in climate at the southern edge of the Sahara* (No. 5). Stichting voor Bodemkartering Wageningen.

Tufa, M., Melese, A., & Tena, W. (2019). Effects of land use types on selected soil physical and chemical properties: the case of Kuyu District, Ethiopia. *Eurasian journal of soil science*, *8*(2), 94-109.

Ukut, A. N., Akpan, U. S., & Udoh, B. T. (2014). Characterization and classification of soils in steep-sided hills and sharp-crested ridges of Akwa Ibom State, Nigeria. *Net Journal of Agricultural Science*, *2*(2), 50-57.

Uzu, F.O., Orimoloye, J.R., and Ugwa, I.k. (2003) Characteristics and Agricultural Potentials of Soils of the Floodplains of North-western Nigeria. *Land degradation, Agricultural Productivity and Rural Poverty: Environmental Implications.* Proceedings of the 28th Annual Conference of Soil Science Society of Nigeria. University of Benin, Benin City, p.325-336.

Van Wambeke, A.R. (1962). Criteria for classifying tropical soils by age. Journal of Soil Science, 13, 124-132

Wali, S. U., Umar, K. J., Abubakar, S. D., Ifabiyi, I. P., Dankani, I. M., Shera, I. M., & Yauri, S. G. (2019). Hydrochemical characterization of shallow and deep groundwater in Basement Complex areas of southern Kebbi State, Sokoto Basin, Nigeria. *Applied Water Science*, *9*(8), 1-36.

Weil, R. R., & Brady, N. C. (2017). The nature and properties of soils (global edition). *Harlow: Pearson*.

Wilding, L. P. (1985). Spatial variability: its documentation, accommodation and implication to soil surveys. In *Soil spatial variability, Las Vegas NV, 30 November-1 December 1984* (pp. 166-194).

Zhu, Q., & Lin, H. (2011). Influences of soil, terrain, and crop growth on soil moisture variation from transect to farm scales. *Geoderma*, *163*(1-2), 45-54.

Zinck, J. A., Metternicht, G., Bocco, G., & Del Valle, H. F. (2013). Geopedology. *Lecture Notes*.

Zonneveld, I.S. (1999), A geomorphological based banded ('tiger') vegetation pattern related to former dune fields in Sokoto (Northern Nigeria) *Catena 37. 45–56.*