

Physicochemical Properties as Affected by Concretionary Nodules of Oxidic Rhodustalf of Southern Guinea Savanna Agroecological Zone of Nigeria

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DOI: <https://doi.org/10.51244/IJRSI.2024.1110059>

Received: 10 October 2024; Accepted: 18 October 2024; Published: 20 November 2024

ABSTRACT

Diverse concretion types are prevalent across diverse soil types in the savanna region. However, its chemistry, mineralogy, profile, dimension, and abundance can significantly vary, influenced by the distinct weathering processes characteristic of each location. The accumulation of concretions in soil can have a considerable impact on its physical and chemical properties, especially at high concentrations. This effect largely depends on the chemical composition and mineralogy of the oxide components present [1]. Despite the potential significance of these effects, the influence of concretionary nodules on soil physicochemical properties remains underexplored. Existing studies are few and often lack detailed insights. Therefore, this study aims to investigate the physicochemical properties of soil influenced by concretionary nodules in the Oxidic Rhodustalf of Southern Guinea Savannah, Nigeria. Results obtained from our analysis revealed interesting variations obtained. Three distinct textural classes were identified regarding physical properties: Sandy Loam, Sandy Clay Loam, and Loamy Sand. At various sites, the soil generally exhibited a slightly higher clay content (20.06 %) and sand content (74.04 %) compared to the concretions. However, the concretions had a higher silt content, at 7.34 %. Obbo Ile recorded the highest clay content (24.09 %) but the lowest silt and sand content among the locations. In contrast, Owu Isin had a significantly higher sand content (75.04 %). Clay content increased with depth, while sand content decreased. Although silt content generally increased, it dropped significantly after the 90-120 cm depth. Analysis of the chemical properties revealed significant variations ($p < 0.05$) for the parameters evaluated. The conductivity, pH in water, and CaCl_2 were higher in Soil than in concretions. Similarly, the elements Na, K, Ca, and Mg also displayed higher values in soil. OM, SOC, Ex. Acidity and CEC except N (%) were significantly ($p < 0.05$) higher in soil than in concretions. The pH in H_2O was stable across depths and locations, with the highest value at 60-90 cm in Obbo Ile for soil and the lowest at the same depth in Owu Isin for concretions. pH measured with CaCl_2 mirrored this trend, peaking at 5.93. Conductivity decreased with depth, reaching its highest at 0-30 cm in Osi for soil. Base cations (Na, K, Ca, and Mg) were significantly higher in Obbo Ile and Osi compared to Owu Isin, with values consistently higher in soil than in concretions. Total nitrogen was highest (1.31 %) at 90-120 cm in Obbo Ile's concretions. Soil organic carbon (SOC) peaked at 1.11 % at 0-30 cm in Owu Ile, and exchangeable acidity was highest at 90-120 cm there. Cation exchange capacity (CEC) was highest (0.35 meq/100 g) at 30-60 cm in Osi's soil.

Keywords: Concretions, Nodules, Physical and Chemical properties, Guinea Savannah, Equilibrium Concentration.

INTRODUCTION

Concretionary nodules are integral components of the soil matrix, arising from the convergence of multiple, simultaneous geochemical and physical processes. These nodules are characterized by irregular and discontinuous growth patterns, with varying formation rates across different parts of the same nodule [2]. The internal structure of these nodules reflects a complex network of interactions within the soil system, embodying the cumulative effects of soil formation and environmental conditions [3]. Typically, nodules exhibit concentric, though not always continuous, layers that differ in their manganese (Mn) and iron (Fe) content, with the Mn-rich layers being bright or metallic and the Fe-rich layers appearing dull or black [4,5].

For instance, forming Fe-Mn concretions and nodules is a gradual process occurring over extended periods, closely tied to the pedogenetic development of soils. These structures' shape, composition, and internal distribution patterns reveal the redox history of the soil environment [1]. Typically ranging in size from 1 to 15 cm in diameter [4,6], nodules are heavily influenced by the predominant source solutions from which they derive their composition [2].

Fluctuations in soil redox potential play a crucial role in the formation of these concretions. Under saturated conditions, iron and manganese oxides are reduced and dispersed throughout the soil. As the soil dries, oxygen levels increase, leading to the oxidation and reprecipitation of these elements, which line or occlude the soil's pores [1]. The resultant concretions encapsulate a variety of soil matrix components, including skeletal grains, clay minerals, and pore spaces, which are cemented by the precipitated oxides. This process leads to a geochemical enrichment of iron and manganese oxides within the concretions, differentiating them from the surrounding soil matrix [7,8,9].

The distribution of nodules is highly variable, both regionally and locally, even within small-scale areas. For instance, in areas with a high overall abundance of nodules, coverage can vary significantly within a few hundred square meters, with some areas exhibiting no nodules and others having coverage exceeding two-thirds [10]. The spatial arrangement and frequency of these concretions within the soil matrix significantly impact soil porosity and its capacity to retain air and water. Dense accumulations of large concretions can disrupt pore networks and impede water infiltration, leading to increased surface runoff and exacerbating soil erosion, particularly on sloped surfaces [11]. In contrast, smaller, more evenly distributed concretions tend to have a less pronounced impact on soil porosity, thus mitigating negative effects on water movement and erosion.

Some studies highlight the structural differences between concretions and nodules, with concretions possessing well-defined concentric rings around a central point or plane, indicative of different pedogenetic processes [12,13]. Further research has identified ferrihydrite, goethite, or hematite as the primary mineral components of concretions, with variable amounts of aluminum substituting within the structure [14,15]. These minerals' presence and specific compositions underscore the complexity of concretions and their significant influence on the chemical and physical properties of soils. Concretions from Greek Alfisols, for example, are enriched in thermodynamically unstable Fe oxides, further illustrating their dynamic role in soil processes [8].

MATERIALS & METHODS

A brief description of the Study Area

The research involved collecting soil samples using specialized equipment from various locations within the Southern Guinean savannah. Specifically, samples were collected from three communities in Kwara State: Owu Isin (latitude 08°16.58'N, longitude 05°55'6"E), Obbo-Ile (latitude 08°77.5'N, longitude 05°18'7"E), and Osi (latitude 07°3'6"N, longitude 05°08'7"E). These areas are located within the Southern Guinea savannah ecological zone of Nigeria.

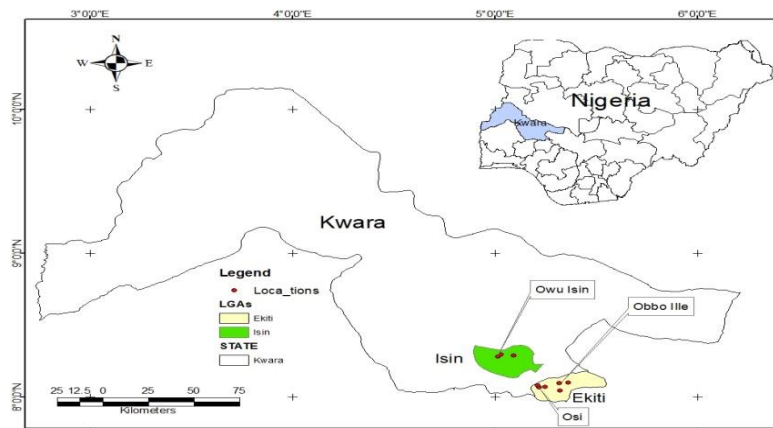
Climate of the Study Area

The study areas experience a bimodal rainfall pattern, receiving approximately 1600 mm of precipitation, with

peak periods in July and September and a dry spell in August. The mean daily maximum temperature ranges from 28°C to 34°C, while the mean daily minimum temperature fluctuates between 24°C and 26°C. Relative humidity is about 75% during the day and rises to 96% at night.

Land Use of the Study Areas

The study areas are predominantly characterized by arable and livestock farming as the main land-use types. Subsistence farming is prevalent in arable farming, involving intensive and continuous cultivation practices. The primary crops grown in these areas include sorghum, maize, cowpea, groundnuts, soybeans, and vegetables.



Map of the Study Area

Soil Mineralogy of the Study Areas

The study areas are defined by a combination of crystalline Precambrian basement complex rocks, including both metamorphic and igneous formations, along with sedimentary rocks [16]. In some locations, these rocks are overlain by substantial deposits of ferruginous tropical soils. The region is characterized by highly weathered red and yellowish-brown ferralsols in various spots. The soil profile typically consists of a moderately deep, reddish sandy clay loam with plinthite at depth, well-drained, and identified as Ferric Luvisol [17] and Oxic Rhodustalf [18]. Overall, the soil is a leached tropical ferruginous type, resting on a deeply weathered Precambrian basement complex, with ironstone gravels and ferruginized sandstone commonly present at higher elevations, which contribute to the formation of well-drained soils.

Soil Sampling Method

Soil samples were collected from three communities experiencing poor fertilizer efficacy. Farms with prominent concretionary nodules were selected within these communities. Soil profiles were excavated on these farms, and samples were taken at various depths: 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, and 120-150 cm. Each profile was carefully delineated with horizon boundaries and measured. Comprehensive laboratory analyses were performed on samples from each genetic horizon, with triplicate samples for accuracy. The samples were air-dried, sieved, and stored for subsequent analysis of soil nutrient content and texture composition.

Separation of Concretionary Nodules

After air-drying and sieving through a 2-mm mesh, the soil samples were divided into concretionary nodules and fine soil fractions. Both fractions were then ground to a particle size of 2 mm or smaller and stored in plastic cups for further analysis.

Laboratory Analyses

To comprehensively evaluate the physical and chemical properties of concretionary nodules and fine soils, we

employed internationally standardized analytical techniques. These analyses included particle size distribution, soil pH, organic carbon (OC) content, exchangeable bases (Ca^{2+} , Mg^{2+} , K^{+} , and Na^{+}), conductivity, exchangeable acidity, nitrogen (%), and cation exchange capacity (CEC).

Particle Size Distribution

Soil particle size distribution was assessed using the modified Bouyoucos hydrometer method, as delineated by Gee and Or [19]. A 40 g soil sample was transferred to a beaker and mixed with 60 mL of water. To ensure thorough dispersion of soil particles and removal of organic matter, 100 mL of a 5% sodium hexametaphosphate (Calgon) solution was introduced. The mixture was allowed to stand for approximately 10 minutes, followed by vigorous agitation with a mechanical stirrer for 30 minutes. The resulting suspension was carefully decanted into a graduated sedimentation cylinder, with distilled water used to rinse the beaker and adjust the cylinder volume to 1 liter. The temperature of the suspension was recorded upon reaching equilibrium. The suspension was then homogenized using a plunger, and hydrometer readings were obtained at 5 minutes and 5 hours to determine the clay and silt fractions. Following the final hydrometer measurement, the suspension was filtered through a 45- μm sieve. The retained particles were washed with distilled water, dried in an oven at 105 °C for 24 hours, and classified as the sand fraction. Blank hydrometer readings of the sodium hexametaphosphate solution were also recorded at equivalent intervals. The particle size distribution was subsequently computed using the provided formulas.

$$(\text{clay} + \text{silt})\% = \frac{5\text{mins hydrometer reading} - \text{correction for temperature} \times 100}{\text{Oven dry mass of sample}} \dots\dots\dots (1)$$

$$(\text{clay})\% = \frac{5\text{hours hydrometer reading} - \text{correction for temperature} \times 100}{\text{Oven dry mass of sample}} \dots\dots\dots (2)$$

$$(\text{Silt}) \% = (1) - (2) \dots\dots\dots (3)$$

$$(\text{Sand})\% = \frac{\text{oven dry weight of particles retained on } 45\mu\text{m sieve} \times 100}{\text{Oven dry mass of sample}} \dots\dots\dots (4)$$

The temperature effects on the soil particles were accounted for using the relation provided by Day (1966). Thus, for every 1-°C rise in temperature above 19.5 °C, there is an increase of 0.3°C in the density of the particles in suspension.

Correction for temperature = blank hydrometer reading – increase in weight of particles.

Soil pH and Electrical Conductivity

The soil pH was assessed using a glass electrode pH meter, as per the method delineated by Hendershot and Lavkulich [20]. A soil-to-water ratio of 1:1 was employed, wherein 20 g of soil was placed in a 50 mL beaker, and 20 mL of deionized water was added. The suspension was agitated for 30 minutes to ensure thorough mixing and then left to equilibrate at ambient temperature. The pH meter was pre-calibrated with standard buffer solutions of pH 4.0 and 7.0 to ensure accuracy. The calibrated pH electrode was subsequently inserted into the supernatant to obtain the pH measurement of the soil sample. In addition, the electrical conductivity (EC) was determined using the same suspension. After calibrating the conductivity meter, the electrode was immersed in the supernatant to measure the EC, reflecting the soil's soluble ion concentration.

Exchangeable Cations

A 5 g soil sample was precisely measured and placed into an extraction bottle. To extract exchangeable cations, 50 mL of a 1M ammonium acetate (NH_4OAc) solution, buffered to pH 7, was added to the sample. The extraction bottle was then subjected to vigorous agitation on a mechanical shaker for one hour, ensuring thorough interaction between the soil and the extractant. Post-extraction, the suspension was filtered using Whatman No. 42 filter paper to separate the solid and liquid phases. The resultant filtrate was collected in clean, labeled containers for analysis. The exchangeable calcium and magnesium concentrations in the filtrate

were quantitatively determined using an Atomic Absorption Spectrometer (AAS), offering high sensitivity and specificity for these elements.

Potassium (K) determination

The flame photometer was calibrated such that a concentration of 10 mg/kg of potassium (K) produced a full-scale reading of 100. Following calibration, the flame photometer was utilized to determine the potassium concentration in a 10 mL sample. The resulting data were then used to calculate the total potassium content in the soil, as outlined in the formula below:

$$\text{Exchangeable K}(\text{Cmolkg}^{-1}\text{soil}) = \frac{W \times \text{vol. of Extract} \times 10^3 \text{ (g)} \times 10^2 \text{ (cmol)} \times Z}{\text{Aliquot} \times \text{Weight of soil sample(g)} \times 10^6 \text{ (\mu g)} \times H} \dots\dots(5)$$

Where:

W = Flame photometer reading for K (μg/mL)

Z = Charge on K

H = Atomic mass of K

Sodium (Na) determination

The flame photometer was calibrated such that a concentration of 10 mg/kg of sodium (Na) resulted in a full-scale deflection of 100. After calibration, the photometer was used to measure the sodium concentration in a 10 mL aliquot. The obtained result was then applied to calculate the total amount of sodium present in the soil, as demonstrated by the formula below.

$$\text{Exchangeable Na}(\text{Cmolkg}^{-1}\text{soil}) = \frac{Y \times \text{vol. of Extract} \times 10^3 \text{ (g)} \times 10^2 \text{ (cmol)} \times D}{\text{Aliquot} \times \text{Weight of soil sample(g)} \times 10^6 \text{ (\mu g)} \times F} \dots\dots(6)$$

Where:

Y = Flame photometer reading for Sodium (μg/mL)

D = Charge on Na

F = Atomic mass of Na

Calcium (Ca) Determination

Calcium was measured from the filtered solution using an Atomic Absorption Spectrophotometer (AAS). The instrument was calibrated with standard calcium solutions containing concentrations of 2, 6, and 10 μg/mL at a wavelength of 422.7 nm, with a slit width of 0.07 nm and a current of 10 A. The values obtained were then used in the formula below to estimate the amount of calcium present in the soil sample(s):

$$\text{Ca}(\text{Cmolkg}^{-1}\text{soil}) = \frac{A \times \text{vol. of Extract} \times 10^3 \text{ (g)} \times 10^2 \text{ (cmol)} \times B}{\text{Aliquot} \times \text{Weight of soil sample(g)} \times 10^6 \text{ (\mu g)} \times C} \dots\dots\dots(7)$$

Where:

A = AAS reading (μg/mL)

B = Charge on Ca

C = Atomic mass of Ca

Magnesium (Mg) Determination

Magnesium (Mg) was determined from the filtered solution using the Atomic Absorption Spectrophotometer (AAS). The instrument was calibrated with standard magnesium solutions of 0.2, 0.6, and 1.0 µg/mL, at a wavelength of 422.7 nm, with a slit width of 0.07 nm and a current of 10 A. The obtained readings were then used in the formula below to estimate the amount of magnesium present in the soil sample(s):

$$Mg(Cmolkg^{-1}soil) = \frac{M \times \text{vol. of Extract} \times 10^3 (g) \times 10^2 (cmol) \times G}{\text{Aliquot} \times \text{Weight of soil sample}(g) \times 10^6 (\mu g) \times Q} \text{-----}(8)$$

Where:

M = AAS reading (µg/mL)

G = Charge on Mg

Q = Atomic mass of Mg

Exchangeable Acidity (H⁺ and Al³⁺)

Aluminium and hydrogen ions were extracted from soil samples using 1 M KCl, as described by Thomas [21]. Approximately 10 g of soil was transferred to a 100 mL extraction bottle, and 50 mL of 1 M KCl solution was added. The bottle was placed on a mechanical shaker and agitated for 30 minutes. Following agitation, the soil suspension was filtered through Whatman No. 40 filter paper into a clean, empty bottle. A 25 mL aliquot of the filtrate was pipetted into a 100 mL conical flask, and 2-3 drops of phenolphthalein indicator were added. The solution was titrated with 0.01 M NaOH until a persistent pink endpoint was reached, and this titre was recorded as the combined amount of H⁺ and Al³⁺. To measure aluminium specifically, 10 mL of NaF was added to the solution at the endpoint, and the solution was then back-titrated with 0.01 M HCl until the endpoint became colorless. The titre value from this back-titration was recorded as the amount of Al³⁺.

Effective cation exchange capacity (ECEC) and base saturation

The effective cation exchange capacity is equal to the sum of the exchangeable (Ca²⁺, Mg²⁺, Na⁺, K⁺, H⁺, and Al³⁺. (i.e., ECEC = Ca²⁺ + Mg²⁺ + Na⁺ + K⁺ + H⁺ + Al³⁺) (9)

Base saturation was calculated as the sum of bases (Ca, K, Mg, and Na) expressed as a percentage of effective CEC.

Statistical Analysis

Significant differences in physicochemical properties of soil and bulk soil with concretions, sieved soil without concretions, and the concretions alone were investigated using an ANOVA. Statistical analyses were conducted utilizing Excel 2007 [22] and SAS Statistical Software version 9 (2002).

RESULT

Physical properties of the soils under the influence of concretion nodules in the study area.

Main Effect of Concretionary Nodules on Soil Physical Properties in the Study Areas

The effect of concretionary nodules on soil physical properties at two distinct sites is detailed in Table 1. It shows that the soil has higher clay (20.06 %) and sand (74.04 %) content compared to the concretions, with significant differences between the means. In contrast, the silt content is significantly higher in the concretion sites (7.34 %) than in the soil sites (5.97 %). Despite these differences, both the soils and concretions share the same textural classification of Sandy Loam.

Main Effect of Location on Soil Physical Properties in the Study Areas

All three locations were classified under the same textural class, yet they exhibited significant differences in soil particle proportions, as shown in Table 2. Obbo Ile had the highest clay content at 24.09 %, followed by Owu Isin at 18.89 % and Osi at 18.86 %. Osi had the highest silt content at 8.09 %, whereas Obbo Ile had the lowest silt content at 5.81 %. Additionally, Osi had the lowest sand content at 70.10 %, while Owu Isin recorded the highest sand content at 75.04 %.

Main Effect of Soil Depth on Soil Physical Properties in the Study Areas

Table 3 assesses the main effect of soil depth on soil physical characteristics. Soil depths of 0-30 cm, 30-60 cm, and 60-90 cm all exhibited the same textural class. However, at depths of 90-120 cm and 120-150 cm, the textural class shifted to Sandy Clay Loam. Significant variations in soil particle proportions were observed with depth. The 90-120 cm depth had the highest clay content at 22.47 %, while the 0-30 cm depth had the lowest clay content at 16.25 %. A similar trend was noted for silt, with the highest content at 90-120 cm (10.13 %) and the lowest at 0-30 cm (5.17 %). Conversely, the sand content was highest at 0-30 cm (78.58 %) and lowest at 90-120 cm (67.40 %).

Interaction Effect of Farm Sites and Location on Soil Physical Properties in the Study Areas

The interaction effect of farm site and location on the study area is summarized in Table 4. All sites, except Obbo Ile at the concretion sites, exhibited the same textural class of Sandy Loam. However, there were significant differences in the proportions of soil particles. Obbo Ile had the highest clay content at both soil (22.94 %) and concretion (25.20 %) sites, while the lowest clay content was observed at the concretion sites in Owu Osin (14.73 %). The highest silt content was recorded in Osi at the concretion sites, which was 3.61% higher than the highest silt value recorded at the soil sites in Obbo Ile (6.44 %). Conversely, the lowest silt content was found in Obbo Ile at the concretion sites (5.19 %). Regarding sand content, the highest values were recorded in Owu Osin at the soil sites (78.48 %), followed by the same location at concretion sites. Overall, the lowest sand content was recorded in Obbo Ile, with a value of 69.61 %.

Interaction Effect of Sites and Soil depth on physical properties in the Study Areas

The interaction effects of sites and soil depth, as detailed in Table 5, revealed significant differences. At soil sites, the depths of 0-30 cm, 30-60 cm, and 60-90 cm all exhibited the same textural class of Sandy Loam, whereas the depths of 90-120 cm and 120-150 cm were classified as Sandy Clay Loam. Concretion sites generally followed a similar textural classification at all depths, except for the 120-150 cm depth, which was also classified as Sandy Clay Loam.

Significant variations were observed in the proportions of soil particles. The highest clay content was recorded at the soil sites with a depth of 120-150 cm, reaching 25.58 %. In contrast, the lowest clay content was found at the 30-60 cm depth at both soil (15.49 %) and concretion (15.46 %) sites. The highest silt content of 11.61 % was observed at the 60-90 cm depth at concretion sites, followed by 7.20 % and 7.27 % at the 30-60 cm depth at soil and concretion sites, respectively. The lowest silt content of 4.92 % was recorded at the 90-120 cm depth at soil sites. Regarding sand content, the highest values were observed at the 0-30 cm, 30-60 cm, and 60-90 cm depths at soil sites (77.47 %, 77.31 %, and 78.71 %, respectively) and at the 30-60 cm and 90-120 cm depths at concretion sites (77.27 % and 73.51 %, respectively), with the highest value of 79.71 % recorded at the 0-30 cm depth.

Interaction Effect of Location and Soil depth on soil physical properties in the Study Areas

The interaction effect of site and location on soil physical properties, as outlined in Table 6, revealed significant differences. In Owu Isin, the soil texture class consistently remained Sandy Loam across all depths. In contrast, Obbo Ile displayed a change in texture: Sandy Loam at depths of 0-30 cm and 30-60 cm, transitioning to Sandy Clay at depths of 60-90 cm, 90-120 cm, and 120-150 cm. Obbo Ile had the highest clay content at 32.30 % at the 120-150 cm depth. In Osi, the silt content was notably higher at 15.40 % at 30-60 cm,

whereas Obbo Ile had lower silt content at depths of 90-120 cm and 120-150 cm, with values of 62.23 % and 61.05 %, respectively. The highest silt content of 79.76 % was recorded at the 0-30 cm depth in Osi.

Interaction Effect of Farm Site, Location, and Soil depth on soil physical properties in the Study Area.

Table 7 reveals significant interaction effects of site, location, and depth on soil physical properties. Except for Obbo Ile, where the textural class remained consistent between soil and concretions, variations were observed across other locations and sites. Clay content was higher at deeper depths (90-120 cm and 120-150 cm) across all locations, with the highest value of 34.78 % recorded at a depth of 120-150 cm in concretions. Silt content showed variable trends with depth in both soil and concretions at all three locations. The highest silt content of 10.13 % was found in Osi at 90-120 cm in concretions, while the lowest, at 2.64 %, was measured at a depth of 0-30 cm in Obbo Ile. Conversely, sand content was generally higher than both silt and clay across the study area. The highest sand proportion of 84.57 % was recorded at 0-30 cm in both soil and concretions in Obbo Ile, whereas the lowest sand proportion of 60.78 % was observed at 90-120 cm in soil at Obbo Ile.

Chemical properties of the soils under the influence of concretion nodule

Main Effect of Concretionary Nodules on Soil Chemical Properties in the Study Areas

The analysis of soil and concretions revealed notable differences in chemical properties. Soil sites exhibited significantly higher values for pH in water (6.51) and pH in CaCl₂ (5.08), as well as electrical conductivity (14.47 μ S/cm), compared to the concretions. Conversely, base cations such as sodium (0.65 cmol/kg), potassium (0.60 cmol/kg), calcium (0.60 cmol/kg), and magnesium (0.74 cmol/kg) were found in greater concentrations in the concretions than in the soil. Organic matter content was 64 % higher in soils compared to concretions. Additionally, soil organic carbon, cation exchange capacity (3.01 meq/100 g), and exchangeable acidity (0.42 meq/100 g) were higher in soils. In contrast, nitrogen levels were higher in the concretions, with a concentration of 0.62 % (Table 8).

Main Effect of Location on Soil Chemical Properties in the Study Areas

The chemical properties of the soil across different locations, as detailed in Table 9, displayed significant variations. Osi recorded the highest pH values in both H₂O (6.53) and CaCl₂ (5.42). Electrical conductivity and soil organic matter concentrations increased from Owu Isin, which had the lowest values, to Osi, which had the highest. Total nitrogen levels were lowest in Owu Isin (0.55 %) and highest in Obbo Ile (0.72 %). Base cations sodium (0.60 cmol/kg) and magnesium (0.64 cmol/kg) were notably higher in Osi, while Owu Isin had lower values for these cations (0.38 cmol/kg for sodium and 0.40 cmol/kg for magnesium). Conversely, potassium (0.60 cmol/kg) and calcium (0.59 cmol/kg) were at their highest in Obbo Ile, whereas Owu Isin had the lowest levels of potassium (0.25 cmol/kg) and calcium (0.29 cmol/kg). Soil organic carbon (SOC) was highest in Osi (0.55 %) and lowest in Owu Isin (0.45 %). Exchangeable acidity followed a similar trend to SOC, with lower values in Obbo Ile (0.36 %) and higher values at the other two locations.

Main Effect of Soil depth on soil Chemical Properties in the Study Areas

The impact of soil depth on chemical properties, as shown in Table 10, reveals notable variations. Both conductivity and pH in CaCl₂ decreased with increasing depth throughout the soil profile. The behavior of base cations (Na, K, Ca, Mg) and organic matter (OM) exhibited inconsistent patterns, alternating between increases and decreases across different depths. Nitrogen percentage, soil organic carbon (SOC), and exchangeable acidity initially decreased but then increased at mid-depths before declining again at greater depths. Cation exchange capacity (CEC) followed a similar downward trend, though differences among treatment means were not statistically significant. Overall, Na, K, Ca, Mg, OM, nitrogen, and SOC were more concentrated in the top 0-30 cm and 30-60 cm layers compared to deeper layers.

Interaction Effect of Sites and Location on Soil Chemical Properties in the Study Areas

The interaction effects of sites and locations on various soil properties revealed significant differences. As shown in Table 11, the pH values for both H₂O and CaCl₂ peaked at Obbo Ile with values of 6.69 and 5.53,

respectively. In contrast, lower pH values were found at Owu Isin, with pH H₂O at 5.68 and pH CaCl₂ at 4.12 in concretion sites. Conductivity was notably higher in Obbo Ile and Osi, with the highest value (17.7 μS/cm) recorded in Osi soil samples. For base cations, Na, K, and Ca reached their maximum concentrations in Obbo Ile soil samples (0.82, 0.82, and 0.94, respectively), while the lowest values for Na (0.34) were found in Owu Isin soil samples, and for K (0.20) in Owu Isin, and Ca (0.14) in Osi, all in concretion samples. Magnesium levels were lowest in Obbo Ile concretion samples (0.25). Organic matter (OM), soil organic carbon (SOC), and cation exchange capacity (CEC) were highest in Obbo Ile soil samples, with values of 1.25 %, 0.73 %, and 3.99 meq/100, respectively. OM and SOC were at their lowest in Owu Isin concretion samples (0.41 % and 0.24 %, respectively), while CEC was lowest in Osi concretion samples (1.58 meq/100). Total nitrogen (N) was highest in Obbo Ile concretion samples (0.81 %), and lowest in Osi. Exchangeable acidity was highest in Owu Isin soil samples (0.46), with higher values (0.36) in concretion samples.

Interaction Effect of Sites and Soil depth on chemical properties in the Study Areas

Table 12 highlights the significant effects of site, soil depth, and their interactions on soil chemical properties. A notable interaction ($P < 0.05$) between site and location was observed. For pH in H₂O, values decreased with increasing depth in soil samples but increased in concretions. The highest pH values were recorded at 60-90 cm depth in soil, while the lowest were at 0-30 cm in concretions. A similar trend was noted for pH in CaCl₂, which showed a pronounced decline with depth in both soil and concretions. Conductivity was higher at depths of 0-30 cm and 30-60 cm for both soil and concretions, with soil exhibiting values of 26.50 μS/cm and 15.83 μS/cm, respectively, and concretions showing 23.67 μS/cm and 17.83 μS/cm. Significant differences ($P < 0.05$) in base cations were observed across sites and depths. Sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg) reached their highest values (0.78, 0.73, 0.69, and 0.85, respectively) in soil. In contrast, the lowest values for these cations were found in concretions, with Na (0.26) and K (0.25) at 120-150 cm depth, Ca (0.21) at 0-30 cm and 60-90 cm, and Mg (0.27) at 90-120 cm.

Soil organic matter (SOM) and soil organic carbon (SOC) decreased with depth, with the highest values (1.51 % for SOM and 0.88 % for SOC) at 0-30 cm and 60-90 cm in soil, and the lowest (0.36 % and 0.21 %, respectively) at 120-150 cm in concretions. Total nitrogen showed variable trends across depths in both soil and concretions, peaking at 0.86 % at 90-120 cm and dropping to 0.41 % at 120-150 cm in concretions. Cation Exchange Capacity (CEC) was significantly higher in soil, ranging from 3.55 to 2.76 meq/100, compared to concretions, which ranged from 1.97 to 1.69 meq/100.

Interaction Effect of Location and depth on soil chemical properties in the Study Areas

Significant interactions between site and soil depth on soil chemical properties were observed in the study area. A notable finding is the stable pH in H₂O with increasing depth across all locations. In contrast, pH measured with CaCl₂ consistently declined with depth in both soil and concretions at Owu Isin, Obbo Ile, and Osi (Table 13). Soil conductivity was markedly higher at depths of 0-30 cm, 30-60 cm, and 120-150 cm in Osi compared to other locations, with respective values of 33.75 μS/cm, 23.00 μS/cm, and 12.50 μS/cm. Significant differences ($P < 0.05$) were found for base cations across locations and depths, excluding sodium (Na). Potassium (K) displayed a decreasing trend with depth, peaking at 0.71 at 30-60 cm in Osi and falling to 0.17 at 120-150 cm in Owu Isin. Calcium (Ca) decreased in Owu Ile and Osi but increased in Obbo Ile, with the highest values (0.73) recorded at 120-150 cm in Obbo Ile and the lowest at 90-120 cm in Owu Ile. Sodium (Na) and magnesium (Mg) were highest at depths of 30-60 cm and 0-30 cm, respectively, in Osi, while their lowest values (0.19 for Na and 0.36 for Mg) were recorded at 120-150 cm in Owu Isin.

Both Soil Organic Matter (SOM) and Soil Organic Carbon (SOC) exhibited decreasing trends with increasing depth. Higher values were observed at 0-30 cm and 30-60 cm for SOM, and at 60-90 cm for SOC. Total nitrogen levels peaked at 0.99 % at 90-120 cm in Obbo Ile. Exchangeable acidity was highest at 0.72 at 90-120 cm in Owu Isin and lowest at 0.25 at 30-60 cm in Obbo Ile. The Cation Exchange Capacity (CEC) was highest at 3.28 meq/100 at 30-60 cm in Osi. The interaction between site and soil depth highlights the need for tailored soil management practices. The stable pH in H₂O with increasing depth, contrasted with the declining pH in CaCl₂, indicates varying chemical dynamics within soil profiles. Higher conductivity in Osi at specific depths suggests differences in soil composition and moisture content. The variations in base cations, organic matter,

and nitrogen levels across sites and depths emphasize the importance of localized soil analysis for effective agricultural and land management.

Interaction Effect of Sites by Location by Soil depth on soil chemical properties in the Study Areas

The study revealed significant interactions between farm site, location, and soil depth, impacting various soil chemical properties (Table 14). The pH in H₂O remained relatively stable across different depths and locations for both soil and concretions. The highest pH in H₂O was found at a depth of 60-90 cm in Obbo Ile for soil, while the lowest was at the same depth in Owu Isin for concretions. Similarly, pH measured with CaCl₂ followed a comparable trend, with elevated values observed at the same depth and location for both soil and concretions, reaching up to 5.93. Conductivity exhibited a decreasing trend with increasing depth, peaking at 0-30 cm in Osi for soil. In terms of base cations, Na, K, Ca, and Mg were significantly higher ($P < 0.05$) in Obbo Ile and Osi compared to Owu Isin for soil, with minor differences between locations. These base cations were consistently higher in soil compared to concretions.

Total nitrogen, soil organic carbon (SOC), exchangeable acidity, and cation exchange capacity (CEC) showed variable trends, with both increases and decreases depending on the depth and location. Total nitrogen was highest (1.31 %) at 90-120 cm in concretions at Obbo Ile. SOC reached its peak at 1.11 % at 0-30 cm in Owu Ile for soil, while exchangeable acidity was highest at 90-120 cm at the same location. CEC values were highest (0.35 meq/100) at 30-60 cm in Osi for soil.

DISCUSSION

Enhancing agricultural productivity requires the optimization of crop nutrition, which is closely tied to the chemical, physical, and biological processes occurring in the soil. These processes are influenced by factors such as mineral composition, organic content, fertilization practices, and soil management strategies [23,24]. However, in the Nigerian Guinean Savannah, these efforts are often undermined by widespread soil degradation, largely due to unsustainable land use practices and the impacts of climate stress [25,26,27,28]. Exacerbating these challenges, the highly weathered tropical soils in this region are distinguished by the presence of abundant iron (Fe) and aluminum (Al) oxides, hydroxides, and oxyhydroxides [29,30,31]. These compounds often manifest as concretionary nodules, which are prevalent in such soils [32,33].

The distribution, nature, and abundance of these concretions play a crucial role in determining the soil's nutrient status [29,34]. Concretions are known for their diverse characteristics, which provide valuable insights into their origins and formation processes. These processes can be diagenetic, epigenetic, metamorphic, metasomatic, sedimentary-hydrothermal, or hydrothermal. Concretions can vary in composition such as carbonate, siliceous, phosphoritic, baritic, sideritic, and ferromanganese. In terms of texture, they can range from simple to composite, dense homogeneous, or bedded forms [35,36]. Furthermore, their shapes vary widely, with forms such as globular, flattened, lenticular, columnar, and conical being commonly observed [Dietzel, 2000; 38]. Previous studies have documented a variety of morphological forms for soil concretions and nodules, including spherical, oval, subangular, tubular, and irregular shapes [8,39,40,41,42]. These structures vary in size, typically ranging from 0.25 mm to 4 cm. The mineralogical composition of these concretions is often reflected in their coloration, for instance, darker hues are associated with higher concentrations of manganese (Mn), whereas red, yellow, orange, or brown hues with elevated chroma values are indicative of increased iron (Fe) oxide content [7,43].

Physical Properties

Ferruginous and ferruginous-manganese concretions, for instance, differ significantly from the properties of the host soil horizons, characterized by higher particle density, reduced moisture, lower porosity, and the presence of a significant volume of extremely small pores [44]. Concretionary nodules can have several effects on soil properties. These effects can vary depending on the organization and dispensation of the nodules within the soil profile. Our analysis revealed a noticeable disparity in soil texture and concretions across different depths and locations. While the soil exhibited a slightly higher sand content at 74.04% compared to 73.57% in concretions, this variation was not statistically significant ($P < 0.05$). The clay content was 20.06% in the soil

and 19.16% in concretions, both classified as Sandy Loam (SL). This is consistent with Abekoe & Tiessen's [45] research, which found that soils from upper slopes exhibited higher contents of lateritic nodules and sandy loam textures, while soils from lower slopes had fewer nodules and sandy or silt loam textures. Regardless of location differences, the highest clay content (18.89%) and sand content (75.04%) were discovered in Owu Isin, while Osi had the highest silt content (8.09%). The impact of concretions on soil physical properties is often contingent upon the soil's inherent texture and clay mineralogy. In coarse-textured soils, such as sands, concretions tend to have a minimal effect on porosity and drainage due to the naturally large pore spaces [46]. However, in fine-textured soils with higher clay content, the presence of concretions can further restrict pore space and exacerbate drainage issues.

Chemical Properties

(pH, conductivity, Na, K, Ca, Mg, Ex. Acidity, CEC, N (%), and SOC)

The impact of concretions on soil chemical properties was analyzed comprehensively across various locations and depths. The analysis revealed that concretions contributed to more acidic conditions in the soil, with slightly lower pH values than soils, potentially affecting nutrient availability and soil biological activity. This coincides with the findings of Abdu & Emmanuel [47], who observed that the concretionary nodules were slightly acidic and fairly consistent across all fields, ranging from pH 4.9 to 5.9. These soils are moderate to highly acidic due to the removal of bases, leading to an appreciable accumulation of sesquioxide minerals, such as iron and aluminum oxides, as well as significant amounts of lateritic concretions or nodules [23] (Asomaning *et al.*, 2018; Ahmed *et al.*, 2017; Abdu *et al.*, 2012).

Soils exhibited higher electrical conductivity (14.47 $\mu\text{S}/\text{cm}$) compared to concretions (13.80 $\mu\text{S}/\text{cm}$), indicating greater retention of soluble salts, which is essential for nutrient mobility and plant uptake. Additionally, soils had higher levels of exchangeable bases and a significantly greater cation exchange capacity (3.01 meq/100g) compared to concretions (1.65 meq/100g). This finding contradicts previous studies, which characterized these soils as having low native fertility due to low nutrient content, low CEC, and high phosphorus retention by oxide minerals [48]. Soil organic carbon was higher in soil than in concretions with a significant difference ($P < 0.05$). Abdu & Emmanuel [47] reported similar findings, noting that sieved soils without concretion had more organic carbon content than soils with concretions. Miltner and Zech [49] observed that elevated temperatures can lead to a substantial reduction in organic carbon, with up to 40% of the total organic carbon being released as CO_2 , and can cause significant changes in the composition of organic matter. The organic matter content was significantly higher in soils (1.20%) compared to concretions (0.62%), highlighting the soil's superior capacity for maintaining fertility and structure. Additionally, soils demonstrated slightly elevated levels of exchangeable acidity. This observation is consistent with the work of Potter-McIntyre *et al.* [50], who emphasized that concretions often form within organic-rich environments, where the role of organic matter in guiding mineral precipitation is well-established [51,52,53].

CONCLUSION

The investigation into soil texture and concretions across varying depths and locations provides valuable insights into their influence on soil physicochemical properties. While the observed differences in sand and clay content between the soil and concretions were not statistically significant, the role of concretions in soil structure and functionality remains critical. Concretions are easily identified in soil profiles [54], and their distinct morphological characteristics such as shape, color, and size underscore their heterogeneity compared to surrounding soil materials.

Their distinct morphological features, such as variability in shape, color, and size, highlight the heterogeneity of concretions compared to the surrounding soil matrix. This heterogeneity, along with the potential for recrystallization influenced by climatic factors like humidification [55], suggests that concretions play a complex and significant role in shaping soil physicochemical properties. Given these findings, further research is necessary to expand our understanding of the morphology and fabric characteristics of concretionary nodules and their broader implications for soil health and management.

REFERENCES

1. Gasparatos, D. (2013). Sequestration of heavy metals from soil with Fe–Mn concretions and nodules. *Environmental Chemistry Letters*, 11, 1-9.
2. Verlaan, P. A., & Cronan, D. S. (2022). Origin and variability of resource-grade marine ferromanganese nodules and crusts in the Pacific Ocean: A review of biogeochemical and physical controls. *Geochemistry*, 82(1), 125741.
3. Timofeeva, Y. O., & Golov, V. I. (2007). Sorption of heavy metals by iron-manganic nodules in soils of Primorskii region. *Eurasian soil science*, 40, 1308-1315.
4. Kuhn, T., Wegorzewski, C., Rühlemann, C., Vink, A. (2017). Composition, formation and occurrence of polymetallic nodules. In: Sharma, R. (Ed.), *Deep Sea Mining*. Springer International, New York, NY, pp. 23–63.
5. Benites, M., Millo, C., Hein, J., Nath, B. N., Murton, B., Galante, D., & Jovane, L. (2018). Integrated geochemical and morphological data provide insights into the genesis of ferromanganese nodules. *Minerals*, 8(11), 488.
6. Hein, J.R., Koschinsky, A. (2014). Deep ocean ferromanganese crusts and nodules. In: Scott, S.D. (Ed.), *Treatise on Geochemistry*, 2nd ed., Vol. 13. Elsevier, Amsterdam, the Netherlands, pp. 273–291.
7. Zhang, M., & Karathanasis, A. D. (1997). Characterization of iron-manganese concretions in Kentucky Alfisols with perched water tables. *Clays and Clay Minerals*, 45(3), 428-439.
8. Gasparatos, D., Haidouti, C., & Tarenidis, D. (2004). Characterization of iron oxides in Fe-rich concretions from an imperfectly-drained Greek soil: a study by selective-dissolution techniques and X-ray diffraction. *Archives of Agronomy and Soil Science*, 50(4-5), 485-493.
9. Aide, M. (2005). Elemental composition of soil nodules from two alfisols on an alluvial terrace in Missouri. *Soil science*, 170(12), 1022-1033.
10. Morgan, C. L., Nichols, J. A., Selk, B. W., Toth, J. R., & Wallin, C. (1993). Preliminary analysis of exploration data from Pacific deposits of manganese nodules. *Marine Georesources & Geotechnology*, 11(1), 1-25.
11. Dexter, A. R. (2004). Soil physical quality: Part I - Theory, measurement and application. *Soil and Tillage Research*, 73(1-2), 1-24.
12. Gasparatos, D. (2007). Genesis of Fe–Mn concretions and nodules in alfisols of thessaly (Doctoral dissertation, Agricultural University of Athens).
13. Hickey, P. J., McDaniel, P. A., Strawn, D. G. (2008) Characterization of iron–manganese cemented redoximorphic aggregates on Wetland soils contaminated with mine wastes. *Journal of Environmental Quality* 37:2375–2385. doi:10.2134/jeq2007.0488.
14. Liu, F., Colombo, C., Adamo, P., He, J. Z., Violante, A. (2002). Trace elements in manganese-iron nodules from a Chinese alfisol. *Soil Science Society Am J* 66:661–670.
15. Cornu, S., Deschatrettes, V., Salvador-Blanes, S., Clozel, B., Hardy, M., Branchut, S., LeForestier, L. (2005). Trace element accumulation in Mn-Fe-oxide nodules of a planosolic horizon. *Geoderma* 125:11–24. doi:10.1016/j. Geoderma.2004.06.009.
16. Oriola, E. O., Babatunde, O. R., & Salami, A. A. (2019). Soil Characteristics of Cassava Growing Ferralsols and Ferruginous Soils in Kwara State, Nigeria. <http://repository.rjt.ac.lk/handle/123456789/4993>
17. FAO, (1988). FAO-Unesco Soil Map of the World, Revised Legend. World Soil Resources Report 60. FAO, Rome.
18. USDA, (1975). Soil Taxonomy, a basic system for soil classification for making and interpreting soil surveys. Agricultural Handbook No. 436. USDA, Washington.
19. Gee, G. W., & Or, D. (2002). 2.4 Particle-size analysis. *Methods of soil analysis: Part 4 physical methods*, 5, 255-293.
20. Hendershot, W.H. and Lavkulich, L.M. (1983). Effect of sesquioxides coatings on surface charge of standard mineral and soil samples. *Soil Science Society of America Journal*. 47, 1252- 1260.
21. Thomas, G. W. (1982). Exchangeable cations. *Methods of soil analysis: Part 2 chemical and microbiological properties*, 9, 159-165.
22. Excel (2007). Microsoft Word 2007, Microsoft Inc.
23. Asomaning, S. K., Abekoe, M. K., & Dowuona, G. N. N. (2018). Phosphorus sorption capacity in

- relation to soil properties in profiles of sandy soils of the Keta sandspit in Ghana. *West African Journal of Applied Ecology*, 26(1), 49-60.
24. Spósito, G. (2008). *The chemistry of soils*. Oxford University Press.
 25. Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual review of environment and resources*, 28(1), 205-241.
 26. Macaulay, B. M. (2014). Land degradation in Northern Nigeria: The impacts and implications of human-related and climatic factors. *African Journal of Environmental Science and Technology*, 8(5), 267-273.
 27. Arowolo, A. O., & Deng, X. (2018). Land use/land cover change and statistical modelling of cultivated land change drivers in Nigeria. *Regional environmental change*, 18, 247-259.
 28. Adenle, A. A., Eckert, S., Adedeji, O. I., Ellison, D., & Speranza, C. I. (2020). Human-induced land degradation dominance in the Nigerian Guinea Savannah between 2003–2018. *Remote sensing applications: society and environment*, 19, 100360.
 29. Agbenin, J. O. (2003). Extractable iron and aluminum effects on phosphate sorption in a savanna alfisol. *Soil Science Society of America Journal*, 67(2), 589-595.
 30. Nafiu, A. (2009). Effects of soil properties on the kinetics of desorption of phosphate from alfisols by anion-exchange resins. *Journal of Plant Nutrition and Soil Science*, 172(1), 101-107.
 31. Abdu, N., & Etiene, U. A. (2015). Fifteen-year fallow altered the dynamics of soil phosphorus and cationic balance of a savannah Alfisol. *Archives of Agronomy and Soil Science*, 61(5), 645-656.
 32. Tiessen, H., Frossard, E., Mermut, A. R., & Nyamekye, A. L. (1991). Phosphorus sorption and properties of ferruginous nodules from semiarid soils from Ghana and Brazil. *Geoderma*, 48(3-4), 373-389.
 33. Zhang, G. Y., He, J. Z., Liu, F., & Zhang, L. M. (2014). Iron-manganese nodules harbor lower bacterial diversity and greater proportions of proteobacteria compared to bulk soils in four locations spanning from north to south China. *Geomicrobiology Journal*, 31(7), 562-577.
 34. Bortoluzzi, E. C., Pérez, C. A., Ardisson, J. D., Tiecher, T., & Caner, L. (2015). Occurrence of iron and aluminum sesquioxides and their implications for the P sorption in subtropical soils. *Applied Clay Science*, 104, 196-204.
 35. Baturin, G. N. (2009). Geochemistry of ferromanganese nodules in the Gulf of Finland, Baltic Sea. *Lithology and Mineral Resources*, 44, 411-426.
 36. Saltykov, V. F. (2008). Carbonate concretions in the Middle Jurassic section of the lower Volga R. reaches, *Izvestiya Saratovskogo Universiteta, Ser. Nauki o Zemle*, no. 1, pp. 64–75.
 37. Dexter, A. R. (2004). Soil physical quality: Part I - Theory, measurement, and application. *Soil and Tillage Research*, 73(1-2), 1-24.
 38. Latrille, C., Elsass, F., Van Oort, F., & Denaix, L. (2001). Physical speciation of trace metals in Fe–Mn concretions from a rendzic lithosol developed on Sinemurian limestones (France). *Geoderma*, 100(1-2), 127-146.
 39. Palumbo, B., Bellanca, A., Neri, R., & Roe, M. J. (2001). Trace metal partitioning in Fe–Mn nodules from Sicilian soils, Italy. *Chemical Geology*, 173(4), 257-269.
 40. Childs, C. W., & Leslie, D. M. (1977). Interelement relationships in iron-manganese concretions from a catenary sequence of yellow-grey earth soils in loess. *Soil Science*, 123(6), 369-376.
 41. Gaiffe, M., & Kübler, B. (1992). Relationships between mineral composition and relative ages of iron nodules in Jurassic soil sequences. *Geoderma*, 52(3-4), 343-350.
 42. White, G. N., & Dixon, J. B. (1996). Iron and manganese distribution in nodules from a young Texas Vertisol. *Soil Science Society of America Journal*, 60(4), 1254-1262.
 43. Ram, H., Singh, R. P., & Prasad, J. (2001). Chemical and mineralogical composition of Fe-Mn concretions and calcretes occurring in sodic soils of Eastern Uttar Pradesh, India. *Soil Research*, 39(3), 641-648.
 44. Lysak, L. V., Konova, I. A., Lapygina, E. V., Soina, V. S., & Chekin, M. R. (2019, November). Filtered forms of prokaryotes and bacteriophages in soil concretions. In *IOP Conference Series: Earth and Environmental Science* (Vol. 368, No. 1, p. 012030). IOP Publishing.
 45. Abekoe, M. K., & Tiessen, H. (1998). Phosphorus forms, lateritic nodules and soil properties along a hillslope in northern Ghana. *Catena*, 33(1), 1-15.
 46. Reynolds, W. D. (2008). *Handbook of soil physical properties*. John Wiley & Sons.

47. Abdu, N., & Emmanuel, D. (2017) Soil phosphorus fractions as influenced by concretionary nodules in non-responsive soil in the Nigerian savanna. *Zaria Geographer* Vol. 24, No. 1.
48. Kögel-Knabner, I. (2014). *Treatise on Geochemistry || Dynamics, Chemistry, and Preservation of Organic Matter in Soils.* (), 157–215. doi:10.1016/b978-0-08-095975-7.01012-3
49. Miltner, A., & Zech, W. (1997). Effects of minerals on the transformation of organic matter during simulated fire-induced pyrolysis. *Organic Geochemistry*, 26(3-4), 175-182.
50. Potter-McIntyre, S. L., Chan, M. A., & McPherson, B. J. (2014). Concretion formation in volcanoclastic host rocks: evaluating the role of organics, mineralogy, and geochemistry on early diagenesis. *Journal of Sedimentary Research*, 84(10), 875-892.
51. Banfield, J. F., Welch, S. A., Zhang, H., Ebert, T. T., & Penn, R. L. (2000). Aggregation-based crystal growth and microstructure development in natural iron oxyhydroxide biomineralization products. *Science*, 289(5480), 751-754.
52. Hall, J. S., Mozley, P., Davis, J. M., & Roy, N. D. (2004). Environments of formation and controls on spatial distribution of calcite cementation in Plio-Pleistocene fluvial deposits, New Mexico, USA. *Journal of Sedimentary Research*, 74(5), 643-653.
53. Hazen, R. M. (2010). Evolution of minerals. *Scientific American*, 302(3), 58-65.
54. Zaidel'man, F. R., Nikiforova, A. S., Stepantsova, L. V., Krasina, T. V., & Krasin, V. N. (2014). Concretions in typical chernozem, gleyed chernozem-like, and solonetzic chernozem-like soils of the southern Tambov Lowland. *Eurasian soil science*, 47, 540-555.
55. Khokhlova, O. S., Oleinik, S. A., & Kovalevskaya, I. S. (2000). The distinctions between diagenetic and epigenetic types of carbonate concentrations in the buried Holocene soils of the chernozemic zone.

Table1. Main Effect of Concretionary Nodules on soil Physical Properties in the Study Areas

Farm Sites	%Clay	%Silt	%Sand	Textural Class
soil	20.06 ^a	5.97 ^b	74.04 ^a	SL
concretion	19.16 ^b	7.34 ^a	73.57 ^b	SL

Means with the same superscript along the same column are not significantly different (p>0.05) based on Turkey's test

Table 2. Main Effect of Location on soil Physical Properties in the Study Areas

Locations	Clay	Silt	Sand	Textural Class
	-----%-----			
Owu Isin	18.89 ^c	6.07 ^b	75.04 ^a	SL
Obbo Ile	24.09 ^a	5.81 ^c	70.10 ^c	SL
Osi	18.86 ^b	8.09 ^a	73.05 ^b	SL

Means with the same superscript along the same column are not significantly different (p>0.05) based on Turkey's test SL-Sandy Loam

Table3. Main Effect of Soil Depth on soil Physical Properties in the Study Areas

Soil depth	Clay	Silt	Sand	Textural Class
	-----%-----			
0-30	16.25 ^e	5.17 ^c	78.58 ^a	SL
30-60	16.40 ^d	5.52 ^d	78.08 ^b	SL

60-90	17.75 ^c	6.84 ^b	75.41 ^c	SL
90-120	22.47 ^b	10.13 ^a	67.40 ^e	SCL
120-150	25.17 ^a	5.62 ^c	69.21 ^d	SCL

Means with the same superscript along the same column are not significantly different ($p>0.05$) based on Turkey's test SL-Sandy Loam SCL-Sandy Clay Loam

Table 4. Interaction Effect of Farm Sites and Location on soil physical properties in the Study Areas

Farm Site	Location	Clay	Silt	Sand	Textural Class
		----- % -----			
Soil	Owu Isin	17.05 ^e	5.35 ^e	77.60 ^b	SL
	Obbo Ile	22.94 ^b	6.44 ^c	70.62 ^e	SL
	Osi	20.15 ^c	6.13 ^d	73.72 ^c	SL
concretion	Owu Isin	14.73 ^f	6.79 ^b	78.48 ^a	SL
	Obbo Ile	25.20 ^a	5.19 ^f	69.61 ^f	SCL
	Osi	17.56 ^d	10.05 ^a	72.39 ^d	SL

Means with the same superscript along the same column are not significantly different ($p>0.05$) based on Turkey's test SL-Sandy Loam SCL-Sandy Clay Loam

Table5. Interaction Effect of Sites and Soil depth on physical properties in the Study Areas

Farm Site	Depth	Clay	Silt	Sand	Textural Class
	cm	----- % -----			
Soil	0-30	16.71 ^g	5.82 ^g	77.47 ^c	SL
	30-60	15.49 ⁱ	7.20 ^d	77.31 ^d	SL
	60-90	17.51 ^f	3.78 ^j	78.71 ^b	SL
	90-120	25.01 ^c	4.42 ⁱ	70.57 ^f	SCL
	120-150	25.58 ^a	8.64 ^b	65.78 ⁱ	SCL
Concretion	0-30	15.76 ^h	4.53 ^h	79.71 ^a	SL
	30-60	15.46 ⁱ	7.27 ^c	77.27 ^d	SL
	60-90	19.36 ^e	11.61 ^a	69.03 ^g	SL
	90-120	20.01 ^d	6.48 ^f	73.51 ^e	SL
	120-150	25.17 ^b	6.83 ^e	68.00 ^h	SCL

Means with the same superscript along the same column are not significantly different ($p>0.05$) based on Turkey's test SL-Sandy Loam SCL-Sandy Clay Loam

Table 6. Interaction Effect of Location and Soil depth on soil physical properties in the Study Areas

Location	Soil depth	Clay	Silt	Sand	Textural Class
	cm	----- %-----			
Owu Isin	0-30	15.35 ⁿ	6.29 ^m	78.36 ^a	SL
	30-60	15.99 ^j	8.91 ^b	75.10 ⁱ	SL
	60-90	15.60 ^l	7.40 ^c	77.00 ^f	SL
	90-120	18.63 ^h	5.78 ^k	75.59 ^g	SL
	120-150	16.81 ⁱ	4.25 ^m	78.94 ^d	SL
Obbo Ile	0-30	15.64 ^l	4.71 ^l	79.65 ^c	SL
	30-60	18.82 ^g	5.86 ^h	75.32 ^h	SL
	60-90	21.87 ^d	6.81 ^d	71.32 ^k	SCL
	90-120	31.70 ^b	6.07 ^g	62.23 ⁿ	SCL
	120-150	32.30 ^a	6.65 ^j	61.05 ^o	SCL
Osi	0-30	13.77 ^m	6.47 ^e	79.76 ^b	SL
	30-60	19.68 ^f	15.40 ^a	64.92 ^m	SL
	60-90	15.61 ^k	6.30 ^f	78.09 ^e	SL
	90-120	20.76 ^e	6.52 ^e	72.72 ^j	SL
	120-150	24.36 ^c	5.75 ⁱ	69.89 ^l	SCL

Means with the same superscript along the same column are not significantly different (p>0.05) based on Turkey's test SL-Sandy Loam SCL-Sandy Clay Loam

Table 7. Interaction Effect of farm Site, Location and Soil depth on soil physical properties in the Study Area.

Farm Sites	Locations	Soil depth	% Clay	% Silt	% Sand	Textural class
		cm	----- %-----			
Soil	Owu Isin	0-30	16.76 ⁿ	5.30	77.94 ^c	SL
		30-60	16.27 ^q	9.38 ^d	74.35 ^m	SL
		60-90	15.77 ^s	7.48 ^{gh}	76.75 ⁱ	SL
		90-120	19.52 ^k	3.40	77.03 ^{gh}	SL
		120-150	19.80 ^j	3.17	77.03 ^h	SL
	Obbo Ile	0-30	18.53 ⁿ	6.77 ^{mn}	74.70 ^l	SL
		30-60	18.94 ^l	4.86 ^s	76.20 ^j	SL
		60-90	14.86	6.87 ^l	78.27 ^f	SL

		90-120	32.84 ^b	7.08 ^k	60.08	SCL
		120-150	29.77 ^d	6.65 ^o	63.58 ^t	SCL
	Osi	0-30	17.86 ^o	7.39 ^{hi}	74.75 ^l	SL
		30-60	13.60	3.31	83.09 ^c	LS
		60-90	15.69 ^r	7.25 ^j	77.06 ^{gh}	SL
		90-120	27.63 ^f	9.48 ^c	62.89	SCL
		120-150	25.68 ^g	3.21	71.11 ⁿ	SL
Concretion	Owu Isin	0-30	10.94	5.74 ^q	83.32 ^b	LS
		30-60	13.77	5.33 ^q	80.90 ^d	LS
		60-90	15.55 ^t	7.34 ⁱ	77.11 ^g	SL
		90-120	15.70 ^s	8.45 ^e	75.85 ^k	SL
		120-150	17.67 ^p	7.55 ^g	74.78 ^l	SL
	Obbo Ile	0-30	12.76	2.67	84.57 ^a	LS
		30-60	18.84 ^m	6.85 ^{lm}	74.31 ^m	SL
		60-90	28.81 ^e	6.74 ⁿ	64.45 ^r	SCL
		90-120	30.64 ^c	5.06 ^b	64.30 ^s	SCL
		120-150	34.78 ^a	4.65 ^t	60.57	SCL
	Osi	0-30	23.67 ^h	5.66 ^p	70.67 ^o	SCL
		30-60	13.78	9.63 ^b	76.59 ⁱ	SL
		60-90	15.52 ^t	5.35 ^q	79.13 ^e	SL
		90-120	21.63	11.32 ^a	67.05 ^q	SCL
		120-150	23.05 ⁱ	8.28 ^f	68.67 ^p	SCL

Means with the same superscript along the same column are not significantly different ($p>0.05$) based on Turkey's test SL-Sandy Loam SCL-Sandy Clay Loam LS- Loamy Sand

Table 8. Main Effect of Concretionary Nodules on soil Chemical Properties in the Study Areas

Sites	pH water	pH CaCl ₂	Conductivity (µscm)	Na	K	Ca	Mg	OM	N (%)	SOC (%)	Ex. Acidity	CEC (meq/100)
soil	6.51 ^a	5.08 ^a	14.47 ^a	0.65 ^a	0.60 ^a	0.60 ^a	0.74 ^a	1.20 ^a	0.57 ^b	0.70 ^a	0.42 ^a	3.01 ^a
concretion	6.17 ^b	4.87 ^b	13.80 ^b	0.38 ^b	0.32 ^b	0.24 ^b	0.32 ^b	0.56 ^b	0.62 ^a	0.32 ^b	0.40 ^b	1.65 ^b

Means with the same superscript along the same column are not significantly different ($p>0.05$) based on Turkey's test

Table 9. Main Effect of Location on Soil Chemical Properties in the Study Areas

Locations	pH water	pH CaCl ₂	Conductivity	Na	K	Ca	Mg	OM	N (%)	SOC (%)	Ex. Acidity	CEC
			µscm	----- Cmol/kg-----				----- % -----			Cmol/kg	meq/100
Owu Isin	6.02 ^c	4.41 ^c	10.95 ^c	0.38 ^b	0.25 ^c	0.29 ^c	0.40 ^c	0.78 ^c	0.55 ^b	0.45 ^c	0.43 ^a	1.95 ^b
Obbo Ile	6.46 ^b	5.10 ^b	14.05 ^b	0.58 ^a	0.60 ^a	0.59 ^a	0.55 ^b	0.91 ^b	0.72 ^a	0.53 ^b	0.36 ^b	2.88 ^a
Osi	6.53 ^a	5.42 ^a	17.40 ^a	0.60 ^a	0.54 ^b	0.38 ^b	0.64 ^a	0.95 ^a	0.52 ^b	0.55 ^a	0.43 ^a	2.77 ^a

Means with the same superscript along the same column are not significantly different (p>0.05) based on Turkey's test

Table 10. Main Effect of Soil Depth on Soil Chemical Properties in the Study Areas

Soil depth	pH water	pH CaCl ₂	Conductivity (µscm)	Na	K	Ca	Mg	Na	OM	N (%)	SOC (%)	Ex. Acidity	CEC (meq/100)
0-30	6.21 ^b	5.17 ^b	25.08 ^a	0.57 ^a	0.50 ^b	0.43 ^b	0.57 ^b	0.57 ^a	1.15 ^a	0.72 ^a	0.67 ^a	0.37 ^c	2.6 ^a
30-60	6.27 ^b	4.90 ^c	16.83 ^b	0.60 ^a	0.56 ^a	0.47 ^a	0.60 ^a	0.60 ^a	0.98 ^b	0.51 ^c	0.57 ^b	0.33 ^d	2.6 ^a
60-90	6.14 ^a	5.20 ^a	10.39 ^c	0.44 ^a	0.46 ^c	0.42 ^b	0.46 ^d	0.44 ^a	1.03 ^b	0.66 ^b	0.60 ^b	0.42 ^b	2.4 ^a
90-120	6.38 ^a	4.88 ^d	9.56 ^d	0.55 ^a	0.40 ^d	0.34 ^c	0.49 ^c	0.55 ^a	0.62 ^c	0.65 ^b	0.37 ^c	0.51 ^a	2.4 ^a
120-150	6.42 ^a	4.73 ^e	8.81 ^e	0.43 ^a	0.39 ^d	0.43 ^b	0.50 ^c	0.43 ^a	0.61 ^c	0.43 ^d	0.36 ^c	0.42 ^b	2.7 ^a

Table 11. Interaction Effect of Sites and Location on Soil Chemical Properties in the Study Areas

Sites	Location	pH water	pH CaCl ₂	Conductivity (µscm)	Na	K	Ca	Mg	Na	OM	N (%)	SOC (%)	Ex. Acidity	CEC (meq/100)
soil	Owu Isin	6.37 ^b	4.70 ^e	10.8 ^e	0.34 ^b	0.29 ^d	0.25 ^d	0.51 ^b	0.34 ^b	1.15 ^b	0.48 ^c	0.66 ^b	0.46 ^a	2.05 ^b
	Obbo Ile	6.69 ^a	5.53 ^a	14.9 ^c	0.82 ^a	0.82 ^a	0.94 ^a	0.84 ^a	0.82 ^a	1.25 ^a	0.63 ^b	0.73 ^a	0.37 ^{cd}	3.99 ^b
	Osi	6.47 ^b	5.03 ^d	17.7 ^a	0.80 ^a	0.69 ^b	0.62 ^b	0.86 ^a	0.80 ^a	1.19 ^{ab}	0.61 ^b	0.69 ^{ab}	0.43 ^{ab}	3.60 ^a
concretion	Owu Isin	5.68 ^d	4.12 ^f	1.11 ^e	0.41 ^b	0.20 ^e	0.33 ^c	0.29 ^d	0.41 ^b	0.41 ^e	0.62 ^b	0.24 ^e	0.41 ^{bc}	1.84 ^b
	Obbo Ile	6.23 ^c	5.32 ^b	13.2 ^d	0.34 ^b	0.37 ^c	0.24 ^d	0.25 ^e	0.34 ^b	0.56 ^d	0.81 ^a	0.33 ^d	0.36 ^d	1.76 ^{ab}
	Osi	6.59 ^a	5.17 ^c	17.1 ^b	0.40 ^b	0.40 ^c	0.14 ^e	0.41 ^c	0.40 ^b	0.71 ^c	0.43 ^c	0.41 ^c	0.44 ^{ab}	1.58 ^{ab}

Means with the same superscript along the same column are not significantly different ($p > 0.05$) based on Turkey's test

Table 12. Interaction Effect of Sites and Soil depth on Chemical Properties in the Study Areas

Sites	Soil Depth	pH water	pH CaCl ₂	Conductivity (µscm)	Na	K	Ca	Mg	Na	OM	N (%)	SOC (%)	Ex. Acidity	CEC (meq/100)
soil	0-30	6.47 ^{bc}	5.17 ^b	26.50 ^a	0.70 ^{ab}	0.65 ^b	0.65 ^b	0.77 ^b	0.70 ^{ab}	1.51 ^a	0.61 ^c	0.88 ^a	0.37 ^e	3.34 ^a
	30-60	6.54 ^b	5.11 ^d	15.83 ^d	0.78 ^a	0.73 ^a	0.69 ^a	0.85 ^a	0.78 ^a	1.21 ^b	0.60 ^c	0.70 ^b	0.30 ^f	3.55 ^a
	60-90	6.72 ^a	5.27 ^a	12.17 ^e	0.54 ^{a-d}	0.57 ^c	0.63 ^b	0.65 ^d	0.54 ^{a-d}	1.51 ^a	0.76 ^b	0.88 ^a	0.46 ^{bc}	3.05 ^a
	90-120	6.43 ^{bc}	4.96 ^e	9.00 ^g	0.65 ^{ab}	0.52 ^c	0.46 ^d	0.70 ^c	0.65 ^{ab}	0.89 ^c	0.45 ^d	0.52 ^c	0.54 ^a	3.07 ^a
	120-150	6.39 ^{bc}	4.93 ^f	8.33 ^g	0.60 ^{a-c}	0.53 ^c	0.28 ^e	0.72 ^c	0.60 ^{a-c}	0.88 ^c	0.45 ^d	0.51 ^c	0.43 ^{b-d}	2.76 ^a
concretion	0-30	5.96 ^d	5.17 ^b	23.67 ^b	0.44 ^{b-d}	0.35 ^d	0.21 ^f	0.37 ^f	0.44 ^{b-d}	0.79 ^{cd}	0.83 ^{ab}	0.46 ^{cd}	0.37 ^{de}	1.94 ^b
	30-60	6.00 ^d	4.70 ^h	17.83 ^c	0.42 ^{b-d}	0.38 ^d	0.25 ^e	0.36 ^e	0.42 ^{b-d}	0.75 ^d	0.44 ^d	0.43 ^d	0.36 ^{ef}	1.97 ^b
	60-90	6.10 ^d	5.14 ^c	8.61 ^g	0.34 ^{cd}	0.35 ^d	0.21 ^f	0.28 ^c	0.34 ^{cd}	0.55 ^e	0.57 ^c	0.32 ^e	0.39 ^{de}	1.77 ^b
	90-120	6.33 ^c	4.81 ^g	10.11 ^f	0.45 ^{b-d}	0.28 ^e	0.22 ^f	0.27 ^f	0.45 ^{b-d}	0.35 ^f	0.86 ^a	0.20 ^f	0.48 ^b	1.90 ^b
	120-150	6.44 ^d	4.53 ⁱ	8.78 ^g	0.26 ^d	0.25 ^e	0.28 ^e	0.29 ^f	0.26 ^d	0.36 ^f	0.41 ^d	0.21 ^f	0.41 ^{c-e}	1.69 ^b

Means with the same superscript along the same column are not significantly different ($p > 0.05$) based on Turkey's test

Table 13. Interaction Effect of Location and depth on Soil Chemical Properties in the Study Areas

Location	Soil depth	pH water	pH CaCl ₂	Conductivity (µscm)	Na	K	Ca	Mg	OM	N (%)	SOC (%)	Ex. Acidity	CEC (meq/100)
Owu Isin	0-30	6.17 ^{de}	4.51 ⁱ	17.75 ^c	0.47 ^{a-c}	0.35 ^h	0.36 ^e	0.40 ^{fg}	1.26 ^a	0.64 ^{bc}	0.73 ^a	0.39 ^{de}	2.17 ^{ab}
	30-60	6.00 ^{ef}	4.53 ⁱ	14.00 ^{de}	0.47 ^{a-c}	0.29 ⁱ	0.35 ^{ef}	0.40 ^g	1.15 ^{ab}	0.61 ^{bc}	0.67 ^{ab}	0.36 ^{ef}	2.04 ^b
	60-90	6.00 ^{ef}	4.45 ^j	7.75 ^{ij}	0.25 ^{bc}	0.24 ^{ij}	0.28 ^g	0.44 ^{ef}	0.81 ^{d-f}	0.66 ^{bc}	0.47 ^{d-f}	0.41 ^{c-e}	1.82 ^{ab}

	90-120	5.91 ^f	4.34 ^k	8.25 ^{hi}	0.51 ^{a-c}	0.20 ^{jk}	0.21 ^h	0.39 ^g	0.33 ^h	0.56 ^c	0.19 ^h	0.72 ^a	2.23 ^{ab}
	120-150	6.09 ^{ef}	4.24 ^l	7.0 ^j	0.19 ^c	0.17 ^k	0.24 ^h	0.36 ^g	0.33 ^h	0.26 ^e	0.19 ^h	0.30 ^{fg}	1.46 ^{ab}
Obbo Ile	0-30	6.44 ^c	5.70 ^b	23.75 ^b	0.62 ^{ab}	0.61 ^{cd}	0.53 ^c	0.56 ^d	1.10 ^{bc}	0.90 ^a	0.64 ^{bc}	0.36 ^{d-f}	2.88 ^{ab}
	30-60	6.49 ^{bc}	5.23 ^d	13.50 ^{ef}	0.62 ^{ab}	0.69 ^{ab}	0.54 ^c	0.67 ^b	0.71 ^{e-g}	0.37 ^d	0.42 ^{e-f}	0.25 ^g	2.97 ^{ab}
	60-90	6.49 ^{bc}	5.91 ^a	14.92 ^d	0.56 ^{a-c}	0.63 ^{bc}	0.67 ^b	0.48 ^e	1.02 ^c	0.68 ^b	0.59 ^c	0.35 ^{ef}	2.84 ^{ab}
	90-120	6.40 ^c	5.09 ^f	11.17 ^g	0.51 ^{a-c}	0.46 ^{fg}	0.51 ^c	0.45 ^e	0.87 ^d	0.99 ^a	0.50 ^d	0.37 ^{d-f}	2.50 ^{ab}
	120-150	6.47 ^{bc}	5.17 ^e	6.92 ^j	0.59 ^{ab}	0.59 ^{cd}	0.73 ^a	0.59 ^{cd}	0.83 ^{de}	0.65 ^{bc}	0.48 ^{de}	0.29 ^b	2.99 ^{ab}
Osi	0-30	6.03 ^{ef}	5.31 ^c	33.75 ^a	0.63 ^{ab}	0.55 ^{de}	0.41 ^d	0.77 ^a	1.08 ^{bc}	0.61 ^{bc}	0.63 ^{bc}	0.36 ^{ef}	2.92 ^{ab}
	30-60	6.34 ^{cd}	4.96 ^g	23.00 ^b	0.71 ^a	0.70 ^a	0.54 ^c	0.75 ^a	1.07 ^{bc}	0.57 ^c	0.62 ^{bc}	0.38 ^{de}	3.28 ^a
	60-90	6.77 ^a	5.24 ^d	8.50 ^h	0.51 ^{a-c}	0.50 ^{ef}	0.31 ^{fg}	0.48 ^e	1.26 ^a	0.65 ^{bc}	0.73 ^a	0.52 ^b	2.52 ^{ab}
	90-120	6.83 ^a	5.22 ^d	9.25 ^h	0.62 ^{ab}	0.56 ^{de}	0.31 ^{fg}	0.63 ^c	0.66 ^g	0.40 ^d	0.38 ^g	0.44 ^{b-d}	2.76 ^{ab}
	120-150	6.69 ^{ab}	4.78 ^h	12.50 ^f	0.53 ^{a-c}	0.41 ^g	0.33 ^{e-g}	0.67 ^d	0.69 ^{fg}	0.38 ^d	0.40 ^{fg}	0.48 ^{bc}	2.62 ^{ab}

Means with the same superscript along the same column are not significantly different (p>0.05) based on Turkey's test.

Table 14. Interaction Effect of farm Sites, Location and depth on P fraction in the Study Areas

Farm Sites	Locations	Soil depth	H ₂ O	NaHCO ₃ (mg/Kg)	NaOH (mg/Kg)	1M HCL (mg/Kg)	Conc. HCL (mg/Kg)	0.5M H ₂ SO ₄ (mg/Kg)	NaHCO ₃ (mg/Kg)	NaOH (mg/Kg)	1M HCL (mg/LKg)	Conc. HCL (mg/Kg)
soil	Owu Isin	0-30	0.26 ^{l-n}	268.61	322.99 ^h	200.29 ^{f-h}	1.47 ^{n-p}	1212.63 ^{i-k}	176.09	11.56 ^s	164.05 ^h	0.71 ^b
		30-60	0.24 ^{m-n}	487.00 ^l	342.30 ^f	127.09 ^o	3.66 ^{g-j}	977.76 ^r	443.72 ^f	36.96 ^k	89.06 ^p	0.04 ^{j-l}
		60-90	0.28 ^{k-m}	208.17	192.91 ^p	143.50 ⁿ	4.97 ^{c-f}	1572.55 ^b	148.78	313.68 ^b	113.95 ^l	0.46 ^{cd}

		90-120	0.37 ^j	903.91 ^c	210.54 ^m _n	226.51 ^d	5.10 ^{c-f}	1197.61 ^{jk}	376.85 ^j	39.21 ^g	166.15 ^g	0.49 ^c
		120-150	0.37 ^{dj}	385.95 ^o	185.93 ^q	157.63 ^m	4.62 ^{d-g}	1735.41 ^a	406.53 ^h	31.23 ^l	61.28 ^t	0.01 ^l
	Obbo Ile	0-30	0.24 ^m _o	216.23	388.78 ^b _i	197.61 ^f _i	2.35 ^{l-n}	1376.17 ^e	650.68 ^b	13.78 ^{qr}	216.12 ^c	0.87 ^a
		30-60	0.20 ^{no}	497.90 ^k	216.66 ^l	113.20 ^q	2.01 ^{m-p}	1333.01 ^f	212.07 ^s	14.77 ^q	147.16 ⁱ	0.24 ^{f-i}
		60-90	0.35 ^{jk}	299.06 ^r	178.76 ^r	166.67 ^l _m	3.64 ^{g-j}	1064.11 ⁿ _o	298.68 ^p	41.87 ⁱ	98.20 ⁿ	0.12 ^{i-l}
		90-120	0.28 ^k _m	276.84 ^t	188.73 ^q	202.20 ^e _{-g}	2.67 ^{j-m}	1118.38 ^l _m	477.83 ^e	17.18 ^p	83.90 ^q	0.04 ^{jl}
		120-150	0.47 ⁱ	220.75	158.02 ^s	225.47 ^d	1.09 ^p	1065.72 ⁿ _o	310.64 ⁿ	4.58 ^t	222.78 ^b	0.72 ^h
	Osi	0-30	1.56 ^a	616.68 ^j	14.64	174.07 ^k _l	2.54 ^{k-n}	1416.18 ^d	305.66 ^o	16.72 ^p	212.17 ^d	0.29 ^{e-h}
		30-60	1.24 ^c	905.35 ^c	15.82	188.08 ^{ij}	4.49 ^{d-h}	926.92 ^s	70.66	19.87 ^o	91.65 ^o	0.07 ^{j-l}
		60-90	1.28 ^c	729.06 ^f	368.23 ^d	308.10 ^b _c	1.22 ^{op}	1294.54 ^g	93.00	14.58 ^q	212.84 ^d	0.42 ^{c-e}
		90-120	1.31 ^c	888.72 ^d	251.25 ^j	193.66 ^g _{-i}	2.33 ^{l-n}	941.61 ^s	64.33	201.09 ^d	105.91 ^m	0.23 ^{f-i}
		120-150	1.27 ^c	963.91 ^b	125.13 ^t	204.68 ^e _f	3.16 ^{i-l}	1133.88 ^l	72.67	202.27 ^d	22.36 ^o	0.30 ^{e-g}
concretio n	Owu Isin	0-30	0.22 ^m _o	693.86 ^h	373.68 ^b _{-i}	192.69 ^g _{-i}	2.19 ^{l-o}	1203.10 ⁱ _{-k}	770.06 ^a	36.45 ^k	45.65	0.16 ^{g-k}
		30-60	0.26 ^l _n	212.61	329.13 ^g	174.46 ^k _l	1.63 ^{m-p}	1245.40 ^h	392.38 ⁱ	12.61 ^{rs}	302.79 ^a	0.91 ^a
		60-90	0.33 ^{j-l}	460.10 ^m	202.66 ^o	178.12 ^j _k	4.26 ^{e-h}	1006.89 ^{qr}	543.13 ^c	26.41 ⁿ	56.96	0.03 ^{j-l}
		90-120	0.40 ^{ij}	305.73 ^p	211.68 ^m	29.99 ^r	4.05 ^{f-i}	1091.84 ^m _n	421.96 ^g	25.04 ⁿ	143.98 ^j	0.32 ^{d-f}
		120-150	0.35 ^{jk}	643.69 ^j	116.89	212.32 ^e	5.26 ^{c-e}	1287.18 ^g	338.56 ^l	37.89 ^k	91.37 ^o	0.17 ^{g-j}
	Obbo Ile	0-30	0.16 ^o	107.90	398.55 ^a	133.08 ⁿ	6.54 ^a	1033.55 ^p	342.11 ^k	426.21 ^a	77.79 ^s	0.02 ^{kl}

						o		q				
		30-60	0.24 ^m _n	60.09	207.76 ⁿ	314.61 ^b _c	6.36 ^{ab}	1304.40 ^{fg}	198.94	96.09 ^f	115.88 ^l	0.33 ^{d-f}
		60-90	0.74 ^{gh}	179.88	231.05 ^k	232.04 ^d	5.09 ^{c-f}	1061.02 ^o _p	313.95 ^m	48.18 ^h	143.01 ^j	0.17 ^{g-j}
		90-120	0.67 ^h	276.84 ^t	252.79 ^j	12.59 ^r	4.59 ^{d-g}	1221.19 ^{h-} _j	498.04 ^d	29.21 ^m	97.16 ⁿ	0.02 ^{jk}
		120-150	0.75 ^{fg}	71.67	116.89	127.03 ^o	4.90 ^{c-f}	947.59 ^s	296.17 ^q	29.99 ^{lm}	80.73 ^r	0.04 ^{j-l}
	Osi	0-30	0.82 ^f	442.09 ⁿ	295.05 ⁱ	306.66 ^c	5.98 ^{a-c}	1088.31 ⁿ _o	152.33	39.77 ^j	190.95 ^f	0.68 ^b
		30-60	0.71 ^{gh}	303.51 ^q	216.46 ^l	129.82 ^o	3.46 ^{h-k}	1071.60 ⁿ _o	113.99	197.09 ^e	222.34 ^b	0.65 ^b
		60-90	0.93 ^e	873.72 ^e	13.80	317.68 ^a _b	5.48 ^{a-d}	1229.03 ^{hi}	218.64 ^r	31.24 ^l	163.30 ^b	0.16 ^{g-k}
		90-120	1.40 ^b	968.00 ^a	251.25 ^j	190.67 ^h _i	5.38 ^{b-d}	1183.95 ^k	44.81	40.35 ^{ij}	122.10 ^k	0.25 ^{f-i}
		120-150	1.13 ^d	708.43 ^g	25.13	327.99 ^a	4.02 ^{f-i}	1535.23 ^c	206.82 ^t	291.87 ^c	195.23 ^e	0.15 ^{h-l}

Means with the same superscript along the same column are not significantly different (p>0.05) based on Turkey's