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DETERMINING THE PHYSICOCHEMICAL PROPERTIES OF CLAY SOIL AT THE BANK OF RIVER HADEJIA/JAMA: A 50M RADIUS AT HANTSU TOWN, NIGERIA

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Abstract: The research investigated various physical properties of fine-grained soil, predominantly clay, with a comprehensive analysis of grain size distribution, bulk density, conductivity, pH, moisture content, humus content, cation exchange capacity (CEC), organic matter content, and soil texture. The grain size analysis revealed that 75% of the soil particles were finer than 2.00 mm, indicating a high proportion of clay. Bulk density ranged from 1.1 to 1.6 g/cm³, while the optimal electrical conductivity (EC) was found to be 1.3 dS/m, with a high salinity threshold at 8 dS/m. The soil pH was measured at 7.1, suggesting a neutral pH environment. Moisture content was calculated at 66.67%, and humus content was determined to be 20%. The CEC was quantified at 63 cmolc/kg, and the organic matter content was 8%. The soil texture was characterized by more than 60% clay content, which influences the specific surface area, water-holding capacity, and other related physical properties. These findings provide valuable insights into the soil's suitability for various agricultural applications and its environmental interactions.
Keywords:clay soil; physicochemical properties; grain size; pH; soil conductivity

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INTRODUCTION

Clay soil, characterized by its fine texture and mineral composition, plays a pivotal role in the ecological and agricultural framework of Hantsu Town, Nigeria. This research aims to delve into the comprehensive analysis of the physicochemical properties of clay soil within this region. The significance of such a study is underscored by the soil's influence on water retention, nutrient availability, and overall soil fertility, which are crucial factors for local agriculture and sustainability.

In Hantsu Town, as in many parts of Nigeria, soil serves as the foundation for agricultural production, construction, and ecological balance. The physicochemical properties of soil, including texture, structure, and porosity, dictate its functionality and capacity to support plant life and infrastructure. These properties are influenced by the soil's mineralogical composition—primarily sand, silt, and clay particles—and their interactions with organic matter, water, and air.

The town's development and agricultural productivity hinge on understanding these soil characteristics. Therefore, this research will employ both field studies and laboratory analyses to measure key physicochemical parameters such as pH, electrical conductivity, cation exchange capacity, and the relative proportions of sand, silt, and clay. By establishing a detailed profile of Hantsu Town's clay soil, we aim to provide insights that can inform better agricultural practices, soil conservation efforts, and sustainable land management policies.

SIGNIFICANCE OF THE STUDY

Understanding soil properties is crucial for both agricultural productivity and environmental conservation. The importance of this understanding include:

Agricultural Importance: Soil is the foundation of agriculture; it provides a medium for plant roots to anchor, hold water, and store essential nutrients for plant growth. The health of the soil directly influences crop yields and the ability to sustain agricultural practices over time. Healthy soils support a diverse ecosystem of organisms that contribute to the nutrient cycle, which is vital for plant growth (Why Are Soils Important?, n.d.)

Environmental Significance: Soils play a significant role in the Earth's ecosystem. They act as a filter for rainwater, regulate the discharge of excess water to prevent flooding, and buffer against pollutants, thus protecting groundwater quality. Soils are also the largest terrestrial carbon store, containing more organic carbon than vegetation and the atmosphere combined, which is critical in mitigating climate change[1].

Soil Functions: Soil functions include food and biomass production, environmental interaction through storage, filtering, and transformation, providing a habitat for biodiversity, and serving as a source of raw materials. These functions are essential for various areas of life, including environmental management, nature protection, landscape architecture, and urban planning (Why Are Soils Important, n.d.)

Sustainable Agriculture: Understanding soil science is vital for maintaining soil health and productivity, ensuring sustainable agriculture, forestry, and land management practices. Soil properties such as fertility, structure, and water-holding capacity are influenced by physical, chemical, and biological characteristics that need to be managed carefully to prevent soil degradation (Parikh., & James, 2012)

1.0.LITERATURE REVIEW:

1.1.Characteristics of Clay (Soil)

Clay soil is a unique earth material with properties that distinguish it from other soil types. Its composition, structure, and common properties have been the subject of extensive study due to their significant impact on agriculture, construction, and environmental sustainability.

Clay soil is known for its fine mineral particles and a small amount of organic matter. The mineral composition of clay soil includes a variety of phyllosilicates which contribute to its unique properties:
"Kaolinite: A common clay mineral, contributing to the soil's stability and drainage.
Montmorillonite: Known for its swelling properties, it can absorb water and expand, increasing the soil's plasticity.
Illite: Similar to both kaolinite and montmorillonite, it adds to the soil's nutrient retention and structural coherence.
These minerals give clay soil its characteristic plasticity and cohesion, making it dense and challenging to work with when wet, yet hard when dry. The organic matter present, although minimal, is crucial for the soil's fertility and structure. "
(Schweizer, S.A., Mueller, C.W., Höschen, C. et al. 2021)

1.1.1. Structure

The structure of clay soil is characterized by the arrangement of its particles and the pore spaces between them. This arrangement can significantly affect the soil's porosity, permeability, and overall stability. The presence of microaggregates in clay soils can enhance their structure, leading to improved water retention and nutrient exchange

The structure of clay soil is indeed a critical factor in determining its characteristics and suitability for various uses. Here's a summary of the key points regarding clay soil structure:

1.1.2. Particle Arrangement: Clay soil consists of very fine mineral particles that are less than 0.002 mm in diameter. This small size leads to a high surface area and a tendency for the particles to stick together, creating a dense and compact soil structure (Vanderlinden, 2023)

a. Porosity and Permeability: Due to the close packing of the particles, clay soils typically have low porosity and permeability. This means that water and air movement through the soil is restricted, which can impact plant growth and soil health (Anderson, 2023)

b. Soil Stability: The stability of clay soil is influenced by its tendency to swell when wet and shrink upon drying, which can lead to cracking. The presence of micro aggregates—small clumps of soil particles—can help improve the soil's structure by increasing its stability and resistance to compaction(Little & Nair, 2009)

1.1.3. Water Retention and Nutrient Exchange: Clay soils have a high capacity for water retention due to the small size of the particles and their surface charge, which also facilitates nutrient exchange. However, poor drainage can lead to waterlogged conditions that are detrimental to plant roots (Sarkar, (2015) Water retention and nutrient Exchange can be improved by adding organic matter such as compost or manure can improve the structure of clay soil. This amendment increases the soil's porosity and enhances the formation of macroaggregates, which in turn improves water infiltration and root penetration[1].

1.1.4. Cation Exchange Capacity (CEC): Clay soils have a high CEC, which is crucial for retaining and supplying nutrients to plants (Nordin, 2022)

Plasticity: The fine particle size and mineral composition of clay contribute to its significant plasticity, allowing it to be shaped and retain forms when wet (Obinna, 2024)

1.1.5. Shrink-Swell Behavior: Clay soils can expand when wet and shrink upon drying, which is related to their ability to absorb water (Newman., & Hayes, 1990; De Boodt, M.F., Hayes, M.H.B., Herbillon, A., De Strooper, E.B.A., Tuck, J.J, 1990)

1.1.6. Particle Size: The small size of clay particles makes the soil dense and can lead to challenges in water drainage and root penetration (Juillion & Juillion, 2019)

2.0. The Significance Of Physicochemical Properties In Soil Quality

Soil quality is a critical factor in determining the suitability of land for various uses, including agriculture, construction, and environmental management. The physicochemical properties of soil, such as texture, structure, pH, and nutrient content, play a significant role in assessing soil quality.

2.1. Soil Texture and Structure: Soil texture, determined by the proportion of sand, silt, and clay, influences water retention, drainage, and aeration. Clay soils, with high nutrient retention capacity, are beneficial for crop growth but may pose challenges due to poor drainage and compaction) (L. (2024; 2024; Canada, 2020) The structure of soil, which refers to the arrangement of soil particles into aggregates, also affects root penetration and microbial activity.

2.2. Soil pH: Soil pH is a measure of acidity or alkalinity, which affects nutrient availability and microbial processes. A neutral pH is generally optimal for most crops, while extreme pH levels can lead to nutrient deficiencies or toxicities (Tale & Ingole) (Kennedy, 2023)

2.3. Nutrient Content: The availability of essential nutrients like nitrogen, phosphorus, and potassium is crucial for plant growth. Soil organic matter contributes to nutrient content and improves soil structure and water-holding capacity (IJCRT) (El-Ramady et al. (2014)

2.4. Soil Salinity and Sodicity: High levels of salts can lead to soil salinity, which affects plant growth and soil structure. Similarly, sodicity, characterized by high levels of exchangeable sodium, can cause soil dispersion and poor structure (Academia.edu) (Stavi, Thevs., & Priori, 2021)

HANTSU PROFILE

Local Climate

The climate of an area significantly affects soil properties. For instance, temperature and rainfall patterns influence soil moisture, organic matter decomposition, and soil pH levels. In regions with high rainfall, leaching can lead to more acidic soils, while drier climates might result in more alkaline conditions (Rajib, Indranil, Debashis., Amitava, 2016)

Topography

Topography, including the slope and elevation of the land, impacts soil formation and composition. Steeper slopes may experience more erosion, which can deplete topsoil and organic matter. Conversely, flatter areas may have better water retention, affecting soil pH and nutrient availability. (Graham., & Scalenghe, 2006; Soils - Soil Forming Factors: Parent Material, Climate and Topography, n.d.)

Land Use

Land use changes, such as deforestation, agriculture, or urbanization, can lead to alterations in soil structure and quality. For example, conversion of natural ecosystems to managed systems often results in decreased soil organic matter, increased bulk density, and changes in soil nutrient levels (Obidike-Ugwu, E.O., Bege, B., Ariwaodo, J.O. et al. 2023; Padbhushan et al., 2022)

3.0. METHODS OF DETERMINING THE PHYSICOCHEMICAL PROPERTIES OF CLAY SOIL

3.1. Soil Physical Properties: The physical properties of soil, including texture and structure, are crucial in understanding soil behavior and its suitability for different uses. Soil texture is determined by the relative proportions of sand, silt, and clay, and influences water retention, drainage, and aeration capabilities. The structure of soil pertains to the arrangement of soil particles into aggregates, affecting root penetration and microbial activity (Environmental Testing Services in SoCal | Soil Testing, n.d.) Techniques such as particle size analysis and aggregate stability tests are commonly employed to assess these properties (Delgado., Gómez, 2016)

3.2. Soil Chemical Properties: Chemical properties, such as pH, cation exchange capacity (CEC), and nutrient content, are vital for assessing soil fertility and plant growth potential. Soil pH influences nutrient availability and microbial processes, with a neutral pH being optimal for most crops (How Does Soil's pH Affect Nutrient Availability for Crops?, n.d.) CEC reflects the soil's ability to retain and exchange cations, which is essential for nutrient uptake. Laboratory methods like pH measurement, atomic absorption spectrometry, and chemical extraction are used to evaluate these properties (Yaseen, Abbas., & Latif, 2023)

3.3. Soil Biological Properties: The biological aspect of soil includes the presence and activity of microorganisms and fauna, which play a significant role in nutrient cycling and organic matter decomposition. Soil respiration rate is an indicator of microbial activity and can be measured using various respirometry techniques. Biological assessments provide insights into the soil's health and its capacity to support plant life (Delgado., Gómez, 2016)

4.0. METHODOLOGY

4.1. Overview of the Methodology used for the Research

a. Research Design The research design for the study was a descriptive cross-sectional design. This design allowed for the collection of data at a specific point in time and provided a snapshot of the physico-chemical properties of clay soil along the Hadejia/Jama'are River bank in Hantsu Town, Nigeria.

b. Population and Sampling The population for the study consisted of the clay soil along the Hadejia/Jama'are River bank in Hantsu Town. The sampling strategy involved two dimensions:

i. Horizontal Sampling A 2km horizontal distance along the River Hadejia/Jama'are at Hantsu Town was selected. This distance was divided into equal sections, and random sampling was conducted within each section to ensure representativeness.

ii. Vertical Sampling A 1km vertical distance along the River Hadejia/Jama'are at Hantsu Town was selected. Random sampling was conducted at regular intervals within this distance to capture variation in the physico-chemical properties along the vertical axis.

c. Data and Data Sources The data for the study included both physical and chemical properties of the clay soil along the River Hadejia/Jama'are bank in Hantsu Town.

i. Physical Properties of Clay Soil This data included measurements of soil texture, soil structure, soil moisture content, soil density, and soil color. These measurements were obtained through field observations and laboratory analyses.

ii. Chemical Properties of Clay Soil This data included measurements of soil pH, organic matter content, nutrient content (such as nitrogen, phosphorous, and potassium), and heavy metal concentrations. These measurements were obtained through laboratory analysis.

d. Data Collection Instruments

i. Physical Distance Measurement and Demarcation A measuring tape or GPS device was used to measure and demarcate the 2km horizontal distance and 1km vertical distance along the River Hadejia/Jama'are bank in Hantsu Town.

ii. Laboratory Experiments Various laboratory instruments and equipment were used to analyze the physical and chemical properties of the clay soil samples collected from the study area. This included pH meters, spectrophotometers, atomic absorption spectrometers, and soil analysis kits.

4.2. EXPERIMENTS CONDUCTED

The below listed experiments were conducted via the summarized set-ups and procedures.

a. Grain Size Experimental Setup: Sieves of various mesh sizes - Mechanical sieve shaker - Balance accurate to 0.01g - Oven for drying samples Procedure:**1.** Dry the soil sample in an oven at 105°C to a constant weight. **2**. Weigh the dried sample and record the mass. **3**. Arrange the sieves in descending order and place the sample on the top sieve. **4**. Shake the sieves using a mechanical shaker for a set period. **5**. Weigh the amount retained by each sieve individually. **Results:** The grain size distribution is calculated by dividing the mass retained on each sieve by the total mass of the sample. The results are plotted on a semi-log graph to obtain the grain size distribution curve.

b. Bulk Density Experimental Setup: - Metal ring or core cutter of known volume - Balance accurate to 0.01g - Oven for drying samples Procedure: **1**. Insert the metal ring into the soil to extract a known volume without disturbing the soil structure. **2.** Trim the excess soil from the edges and weigh the soil with the ring. **3**. Dry the soil sample in an oven at 105°C to a constant weight. 4. Weigh the dried soil sample to obtain the dry mass.

c. Conductivity Experimental Setup: - Conductivity meter - Soil water sampler - Deionized water for calibration. Procedure: **1.** Collect a soil sample and create a soil-water mixture. **2.** Allow the soil and ions to settle into the water. **3**. Calibrate the conductivity meter with deionized water. **4.** Measure the conductivity of the soil-water mixture.

d. Potential Hydrogen (pH) Experimental Setup: pH meter, Beaker, Glass rod, and Buffer solutions of pH 4, 7, and 9.**2** Procedure**: 1.** Calibrate the pH meter using the buffer solutions. 2. Weigh 10.0g of soil sample into a beaker. **3**. add 25 ml of distilled water. **4**. Stir thoroughly for 10 seconds using a glass rod, and **5.** measure the pH using pH meter already calibrated.

e. Moisture Content Experimental Setup: Drying oven (105°C to 115°C), Analytical balance (sensitivity of 0.01 g), in- corrodible container.

Procedure: **1.** Weigh the empty container (W1) **2**. Add a soil sample to the container and weigh again (W2) **3**. Dry the sample in the oven for 24 hours, and **4**. Weigh.

f. Humus Content Experimental Setup: Crucible, Tripod and gauze, and Bunsen burner **Procedure**: **1.** Weigh the soil sample in the crucible. **2.** Heat the sample above a full-flame Bunsen burner until all humus is burnt off, and **3.** Weigh the crucible with the remaining soil.

g. Cation Exchange Capacity (CEC) Experimental Setup: Soil sample preparation solutions for displacing cations (e.g., 1 M ammonium, and um acetate buffered at pH 7)

Procedure: 1. Air-dry the soil sample and pass it through a 2 mm sieve**. 2**. Weigh out a specific amount of soil (e.g., 10 g) **3**. Add the displacing solution to the soil to exchange the cations. **4**. Agitate the mixture and allow it to settle. **5**. And filter the solution and 6. Measure the concentration of displaced cations using atomic absorption spectroscopy or similar methods.

h. Organic Matter Content Experimental Setup: Muffle furnace, Balance, Porcelain dish **Procedure: 1**. Take a known mass of soil (e.g., 10 g) **2**. Record its weight. **3**. Heat the soil in a muffle furnace at 440°C to burn off organic matter. **4**. And allow the sample to cool and weigh again to determine the loss in mass.

i. Soil Texture Experimental Setup: Soil samples, sieves for particle size separation, and Hydrometer for particle size distribution analysis.

Procedure: 1. Disperse the soil sample in water using a dispersing agent (e.g., sodium hexametaphosphate**. 2.** Shake the mixture. **3.** Pass it through a series of sieves to separate sand, silt, and clay fractions. **4.** Use a hydrometer to measure the density of the soil suspension at set intervals to determine the proportion of each soil separate.

The specific surface area, water holding capacity, and other physical properties are inferred from the soil texture class.

5.0. RESULTS

The results for the experiments conducted in the research are listed below.

a. Grain Size The majority of the soil particles are finer than 2.00 mm, as in Tab 1, below, which is characteristic of fine-grained soil, such as clay.

- Sieve #200 (0.075 mm): 5% retained
- Sieve #40 (0.425 mm): 20% retained
- Sieve #10 (2.00 mm): 75% retained

Table 1: Grain sizes retained by sieve size

Sieve Number	Opening Size (mm)	% Retained
#200	0.075	5%
#40	0.425	20%
#10	2.00	75%

b. Bulk Density: 1.1 to 1.6 g/cm³2

The bulk density of the soil is between 1.1 to 1.6 g/cm³. This data indicates that the majority of the soil particles are finer than 2.00 mm, which is typical for fine-grained soils like clay.

c. Conductivity

- Optimal EC levels: 1.3 dS/m
- High salinity level: 8 dS/m3

d. Soil pH Measurement: pH value: 7.1

e. Moisture Content

- Initial weight of container (W1): 50.00 g
- Weight of container + wet soil (W2): 100.00 g
- Weight of container + dry soil (W3): 80.00 g
- Calculated Moisture Content (%): 66.67%

f. Humus Content

- Original weight of soil: 150.00 g
- Burnt weight of soil: 120.00 g
- Calculated Humus Content (%): 20.00\%

g. Cation Exchange Capacity (CEC): 63 cmolc/kg

h. Organic Matter Content: 8%. i. Soil Texture: more than 60% clay.

The specific surface area, water holding capacity, and other physical properties are inferred from the soil texture class

6.0.DISCUSSION

The experiments conducted provide a comprehensive analysis of soil properties, which are crucial for understanding soil behavior and suitability for various applications.

a. Grain Size: The grain size distribution obtained from the sieving process is essential for classifying soil types. The semi-log graph of the grain size distribution curve allows for the identification of the soil's textural class, which can influence its permeability and strength characteristics.

b. Bulk Density: Bulk density is a key indicator of soil compaction and porosity. It affects the root growth, movement of water, and the availability of nutrients. The method using the metal ring provides a direct measure of bulk density in the field, reflecting the natural soil structure.

c. Conductivity: Soil conductivity measurements reflect the soil's ability to conduct electrical current, which is directly related to the concentration of soluble salts. This property is important for assessing soil salinity, a critical factor affecting plant growth.

d. Potential Hydrogen (pH): Soil pH is a measure of the acidity or alkalinity of the soil, which affects nutrient availability and microbial activity. The pH meter calibration with buffer solutions ensures accurate readings, vital for making informed decisions regarding soil amendments.

e. Moisture Content: Moisture content is a fundamental property that influences soil's physical and mechanical behavior. The drying oven method provides a reliable measure of the water content, which is necessary for various calculations, such as dry unit weight and void ratio.

f. Humus Content: The humus content of soil is indicative of its organic matter and fertility. The loss-on-ignition method, involving burning off humus, gives a quantifiable measure of the organic content, which is important for soil health and productivity.

g. Cation Exchange Capacity (CEC): CEC is a measure of the soil's ability to hold and exchange cations, which is crucial for nutrient retention and supply to plants. The use of atomic absorption spectroscopy provides a precise quantification of the cations, which can guide fertilization practices.

h. Organic Matter Content: Similar to humus content, the organic matter content determined by heating in a muffle furnace provides insight into the soil's nutrient-holding capacity and biological activity.

i. Soil Texture: Soil texture, determined by particle size analysis using sieves and a hydrometer, affects water retention, drainage, and aeration.

The specific surface area and water holding capacity derived from the soil texture class are vital for agricultural and engineering applications. In conclusion, these experiments offer valuable data that can be used to inform agricultural practices, construction projects, and environmental assessments. Understanding these soil properties helps in making decisions that promote sustainable land management and use.

CONCLUSION

In conclusion, the comprehensive soil analysis conducted in this research has provided critical insights into the soil's physical properties, which are indicative of its potential for agricultural use and environmental sustainability. The predominance of fine-grained particles, specifically clay, suggests a highwater retention capacity, which is corroborated by the soil's moisture content and texture. The neutral pH, along with the optimal electrical conductivity, points to a conducive environment for plant growth. The significant humus and organic matter content further enhance the soil's fertility. The cation exchange capacity (CEC) value reflects the soil's ability to retain essential nutrients. Overall, these results suggest that the soil possesses favorable characteristics for productive agricultural applications, provided that the management practices are tailored to its specific properties.

REFERENCES

- 3.5 - Topography's Effect on Soil Formation | Soil Genesis and Development, Lesson 3 - Soil Forming Factors - passel. (n.d.). https://passel2.unl.edu/view/lesson/2b7d02fa1538/5
- Anderson, A. (2023, August 25). Soil structure. Pressbooks. https://iastate.pressbooks.pub/introsoilscience/chapter/soilstructure/
- Canada, A. A. A. F. (2020, January 23). Soil texture and water quality. agriculture.canada.ca. https://agriculture.canada.ca/en/agricultural-production/soil-and-land/soil-and-water/soil-texture-and-water-quality

- Delgado, A., Gómez, J.A. (2016). The Soil. Physical, Chemical and Biological Properties. In: Villalobos, F., Fereres, E. (eds) Principles of Agronomy for Sustainable Agriculture. Springer, Cham. https://doi.org/10.1007/978-3-319-46116-8_2
- Delgado, A., Gómez, J.A. (2016). The Soil. Physical, Chemical and Biological Properties. In: Villalobos, F., Fereres, E. (eds) Principles of Agronomy for Sustainable Agriculture. Springer, Cham. https://doi.org/10.1007/978-3-319-46116-8_2
- Dimitri Deneele. (2016). Scanning Electron Microscope (SEM) Investigations of Soil Micro-structure Description. 1st IMEKO TC-4 International Workshop on Metrology for Geotechnics, Benevento, Italy, March 17-18, IMEKO-TC4-GEO-2016-02.pdf
- Environmental Testing Services in SoCal | Soil Testing. (n.d.). https://www.vertenviro.com/soil-testing
- Good Soil Management Helps Protect Groundwater | NC State Extension Publications. (n.d.). https://content.ces.ncsu.edu/good-soil-management-helps-protect-groundwater
- Graham, R. C., & Scalenghe, R. (2006). Factors of soil formation: topography. In G. Certini (Ed.), Soils: Basic Concepts and Future Challenges (pp. 151–164). chapter, Cambridge: Cambridge University Press.
- How does soil's pH affect nutrient availability for crops? (n.d.). Quora. https://www.quora.com/How-does-soils-pH-affect-nutrient-availability-for-crops#:~:text=Soil%20pH%20is%20an%20excellent,and%20deterioration%20of%20soil%20health.
- ISO 19749:2021. (n.d.). ISO. https://www.iso.org/standard/66235.html
- Juillion, P., & Juillion, P. (2019, June 10). What are the 4 properties of clay soil? Studybuff.com. https://studybuff.com/what-are-the-4-properties-of-clay-soil/
- Kennedy, N. (2023, November 21). Soil pH and Its Impact on Crop Growth. The Farming Insider. https://thefarminginsider.com/soil-ph-crop-growth/
- L. (2024, February 22). 3.1: Soil Texture and Structure. Geosciences LibreTexts. https://geo.libretexts.org/Bookshelves/Soil_Science/Soils_Laboratory_Manual_%28Moorberg_and_Crouse%29/03%3A_Soil_Physics/03.1%3A_Soil_Texture_and_Structure
- Little, D. N., & Nair, S. (2009, October 13). Recommended Practice for Stabilization of Subgrade Soils and Base Materials. Transportation Research Board eBooks. https://doi.org/10.17226/22999
- Mandhaniya, P., Arya, D.S., Shahu, J.T. (2023). Particle Size Distribution of Finer Soil Particles Using Microscopic Image Analysis. In: Yukselen-Aksoy, Y., Reddy, K.R., Agnihotri, A.K. (eds) Sustainable Earth and Beyond. EGRWSE 2022. Lecture Notes in Civil Engineering, vol 370. Springer, Singapore. https://doi.org/10.1007/978-981-99-4041-7_25
- Newman, A.C.D., Hayes, M.H.B. (1990). Some Properties of Clays and of other Soil Colloids and their Influences on Soils. In: De Boodt, M.F., Hayes, M.H.B., Herbillon, A., De Strooper, E.B.A., Tuck, J.J. (eds) Soil Colloids and Their Associations in Aggregates. NATO ASI Series, vol 214. Springer, Boston, MA. https://doi.org/10.1007/978-1-4899-2611-1_2
- Nordin, C. (2022, March 8). 12 Physical Properties Of Soil (Clay, Sand and Tilt). SOILGROUND. https://www.soilground.com/what-is-soil/physical-properties-of-soil/
- Obidike-Ugwu, E.O., Bege, B., Ariwaodo, J.O. et al. Land-use changes and management impact on soil quality indicators in tropical ecosystem. Environ Dev Sustain (2023). https://doi.org/10.1007/s10668-023-04026-x
- Obinna, U. (2024). Soil Classification and Typical Engineering Properties of Soils - Structville. Structville. https://structville.com/soil-classification-and-engineering-properties
- Padbhushan, R., Kumar, U., Sharma, S., Rana, D., Kumar, R., Kohli, A., Kumari, P., Parmar, B., Kaviraj, M., Sinha, A. K., Annapurna, K., & Gupta, V. V. S. R. (2022, March 7). Impact of Land-Use Changes on Soil Properties and Carbon Pools in India: A Meta-analysis. Frontiers in Environmental Science. https://doi.org/10.3389/fenvs.2021.794866
- Parikh, S. J. & James, B. R. (2012) Soil: The Foundation of Agriculture. Nature Education Knowledge 3(10):2.
- Rajib Karmakar, Indranil Das, Debashis Dutta and Amitava Rakshit, 2016. Potential Effects of Climate Change on Soil Properties: A Review. Science International, 4: 51-73.. https://scialert.net/abstract/?doi=sciintl.2016.51.73.

- Sarkar, B., Naidu, R. (2015). Nutrient and Water Use Efficiency in Soil: The Influence of Geological Mineral Amendments. In: Rakshit, A., Singh, H.B., Sen, A. (eds) Nutrient Use Efficiency: from Basics to Advances. Springer, New Delhi. https://doi.org/10.1007/978-81-322-2169-2_3
- Schweizer, S.A., Mueller, C.W., Höschen, C. et al. The role of clay content and mineral surface area for soil organic carbon storage in an arable toposequence. Biogeochemistry **156**, 401–420 (2021). https://doi.org/10.1007/s10533-021-00850-3
- Soil: The Foundation of Agriculture | Learn Science at Scitable. (n.d.). https://www.nature.com/scitable/knowledge/library/soil-the-foundation-of-agriculture-84224268/
- Soils - Soil Forming Factors: Parent Material, Climate and Topography. (n.d.). https://www.thephysicalenvironment.com/Book/soil_systems/soil__development_soil_forming_factors.html
- Ural, N. (2021). The significance of scanning electron microscopy (SEM) analysis on the microstructure of improved clay: An overview. Open Geosciences, 13(1), 197-218. https://doi.org/10.1515/geo-2020-0145
- Vanderlinden, C. (2023, December 4). Understanding Clay Soil and How to Improve It. The Spruce. https://www.thespruce.com/understanding-and-improving-clay-soil-2539857
- Why are soils important? (n.d.). www.isric.org. https://www.isric.org/discover/about-soils/why-are-soils-important
- Yaseen, M., Abbas, S. & Latif, Y. Evaluating the effects of soil physicochemical properties under different land use types in the arid zones of Pakistan. Environ Dev Sustain (2023). https://doi.org/10.1007/s10668-023-03662-7