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COMPARATIVE ANALYSIS OF SOIL PHYSICAL AND CHEMICAL PROPERTIES IN BICHI AND GAYA FARMS, KANO STATE, NIGERIA

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Abstract

*The degradation of soil fertility is a significant challenge to agricultural productivity in northern Nigeria. This research conducts a comparative analysis of the physical and chemical properties of soils in Bichi and Gaya locations to evaluate their viability for cultivation of groundnut (*Arachis hypogaea* L.). Composite soil samples (0-20 cm) were collected from Bichi and Gaya and analyzed using standardized laboratory techniques for parameters, including texture, BD, pH, EC, OC, OM, nitrogen, phosphorus, sodium, calcium, magnesium, EB, and CEC. The results determined that both soils are classified as loamy sand, but Bichi exhibited a higher BD (1.66 g/cm^3) compared to Gaya (1.46 g/cm^3), reflecting compaction. The soils were found to be slightly acidic (pH: Bichi 6.72; Gaya 6.37) and non-saline ($\text{EC} < 0.05 \text{ ds/m}$) with respective EC values of 0.04 ds/m for Bichi and 0.01 ds/m for Gaya. Both OC and OM levels were low, particularly in Gaya, with Bichi showing values of 0.54 % OC and 0.94% OM and Gaya showing values of 0.34% OC and 0.58% OM. Nitrogen levels were critically low in both areas ($\leq 0.05 \text{ mg/kg}$), measuring 0.05 mg/kg in Bichi and 0.04 mg/kg in Gaya, whereas phosphorus was found to be higher in Gaya (13.91 mg/kg) compared to Bichi (7.48 mg/kg). EB and CEC values were also low, with Bichi recording slightly elevated CEC (3.5 cmol/kg) as compared to Gaya (3.05 cmol/kg). Both locations soils are loamy sand with low OC, nitrogen, and CEC, limiting fertility. Bichi's higher BD and pH favor root growth, while Gaya's higher phosphorus and calcium may enhance nutrient availability. Soil amendments are needed for sustainable cultivation.*

Keywords: Soil Fertility, Loamy Sand, Soil pH, Bichi and Gaya.

Introduction

The condition of soil is crucial for agricultural productivity and environmental sustainability. Variations in the soil's chemical and physical properties directly affect crop growth, nutrient availability, and soil fertility over time (Lai, 2009; Brandy & Weil, 2016). Soil characteristics have a significant impact on farming efficiency, ecological balance, and land management strategies. In Nigeria, and Kano State in particular, the discrepancies in soil traits among different areas affect agricultural yields and farming methodologies. Therefore, evaluating soil nutrient levels is essential for increasing agricultural output and enhancing the economic progress of nations (Haghdar *et al.*, 2012). The chemical and physical attributes of soils are key determinants of their appropriateness for both agricultural and non-agricultural applications. Highly fertile soils not only yield better food, fiber, and fodder but also help in forming natural ecosystems, and improving air and water quality (Griffiths & Philippot 2013).

The fundamental physical and chemical properties of soil are critical in establishing the ability of plants to access water and nutrients. Attributes such as soil texture, soil porosity, and permeability affect water retention, aeration, nutrient transport, and root penetration within the soil. For example, roots must deal with mechanical resistance from the soil structure, meaning that compacted soils can hinder root development and crop yields. Roots tend to grow into macropores existing in the soil, which offer less mechanical resistance and improved access to necessary resources. Conversely, poorly structured or compacted soils can impede root growth, limit water supply, and decrease air circulation due to reduced porosity (Maik *et al.*, 2019).

Soil is vital for the cultivation of plants that provide food for humans and animals (Silver *et al.*, 2021). Optimal levels of soil nutrients are essential for promoting plant growth and achieving maximum yields (Shahane & Shivay, 2021). Additionally, these nutrients are critical in the movement and interactions of water, solutes, and gases within the soils. Typically, soil comprises about 50-60% mineral matter, 25-35% water, 15-25% air, and a small percentage of organic matter (Girvan *et al.*, 2004). The interplay of physical and chemical properties makes soils suitable for a variety of applications.

In Nigeria, especially in semi-arid areas such as Kano State, understanding soil characteristics across different regions is crucial for effective planning in sustainable land use (Musa *et al.*, 2022). This study examines and compares key soil parameters between Bichi and Gaya, two agricultural districts in Kano State, to evaluate their potential for crop production.

Material and Methods

Study Area

The research was conducted at two different sites in Kano State, Nigeria, specifically at Aliko Dangote University of Science and Technology (ADUSTECH), Wudil-Teaching, and Research Farm Gaya and Sabuwar Kasuwa Bichi, Bichi local government area. The Gaya and Bichi sites are situated within the Gaya and Bichi local government area, positioned between latitude 11.7417°N, 12.2341°N and longitude 8.5247°E, 8.24111°E. These local government area covers approximately 613 km², 612 km² and has a projected population exceeding 341,100, 457,700 (2022). The region is classified as a savanna zone, noted for its scattered tree species across a grassland landscape. The trees generally feature broad canopies and often do not exceed 2 meters in height, while the grasses can grow up to 1.5 meters at full maturity (Lawan *et al.*, 2020).

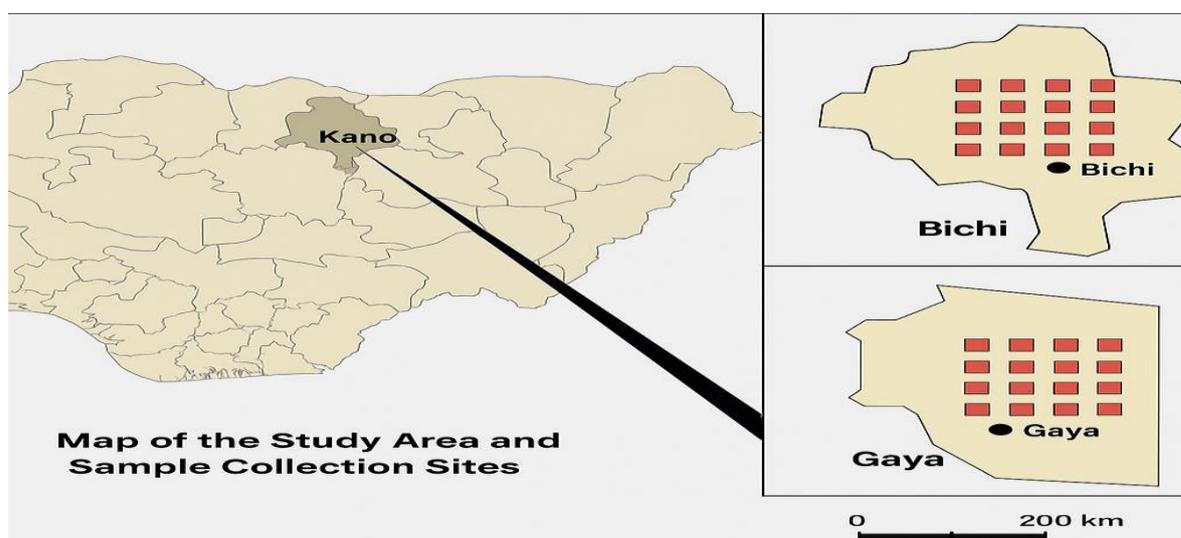


Figure 1: Map of the Study Area and Sample Collection Sites

- Temperature of Bichi and Gaya are located in Kano State, Nigeria, and experience a hot, tropical continental climate. Annual mean temperature of Gaya is 33.2⁰C and Bichi is 33.1⁰C.
- Precipitation of Bichi and Gaya are located in Kano State, Nigeria, the annual rainfall of Gaya is 600 mm and Bichi is 606 mm.
- Geology both Bichi and Gaya are situated within the Nigerian Basement complex, which is typical for much of Kano state. The dominant rock in the areas are; the dominant rocks in Bichi are Quartzite, Schist, Granite, Migmatite-Gneiss complex, Biotite, and Quartz Veins, also the dominate rocks in Gaya are Medium-Grained Granite, Migmatite-Gneiss complex, Schist Belts, pegmatite, and Laterites (Bala *et al.*, 2011; Sabo *et al.*, 2019). Soil formation, the weathering of migmatite, gneiss, schist, and granite produces soils that are typically sandy loam to loamy sand. The soils are generally well-drained, have moderate to low fertility, and are prone to erosion if vegetation cover is sparse. The mineral composition of the parent rocks influences the soil's nutrient content, acidity, and texture (Bala *et al.*, 2011).
- Human activity of Bichi and Gaya, the nature and magnitude of human activity particularly intensive agriculture, deforestation, overgrazing, and urban expansion are major drivers of soil degradation. These activities directly affect soil structure, fertility, and overall ecosystem health.

Soil Sampling and Collection

A total of 144 soil samples were collected, with 72 samples collected from one representative farm at each location. The soil samples were collected systematically using a grid sampling technique to ensure that each area was adequately represented. Each location was divided into equal plots, and each plot is 3m × 3m long = 9 m², and samples were taken at consistent intervals using an auger at a depth of 0-20 cm, which represents the plow layer. To minimize variability, composite samples were created by mixing subsamples from five points within each plot. Each composite sample was subsequently air-dried, sieved through a 2 mm mesh, and placed into labeled containers for laboratory analysis. The analyzed parameters include soil texture, bulk density, soil pH, organic matter content, organic carbon, electrical conductivity, nitrogen, phosphorus, exchangeable bases, and cation exchange capacity (CEC).

Laboratory Method

The physical and chemical properties of the samples were analyzed following the standard laboratory procedures as described by Black (1965). Soil texture was assessed using the hydrometer method (Day, 1965) to determine the proportions of sand, silt, and clay. Bulk density was measured using the core sampler method to measure soil compaction. Cation exchange capacity (CEC) was determined using the ammonium saturation method as per Anderson and Ingram (1993). The analysis of organic carbon was conducted through the Walkley–Black wet oxidation method (Nelson and Sommers, 1982). Total nitrogen was quantified using the micro-Kjeldahl procedure (Bremner and Mulvaney, 1986). The available phosphorus was determined utilizing the Bray No. 1 extraction method (Bray and Kurtz, 1955). Exchangeable bases (Ca, Mg, K, and Na) were analyzed with an atomic absorption spectrophotometer and flame photometer, while soil pH was measured employing the calcium chloride (CaCl₂) method to ensure more precise readings under field conditions.

Data Analysis

Descriptive statistics were conducted to summarize the obtained from the routine tests. Analysis of variance (ANOVA) was followed by Tukey's Honest Significant Difference (HSD) test to separate the means where significant differences ($p \leq 0.05$) were observed. All statistical analyses were performed using GenStat 17th edition.

Results and Discussion

Table 1: Physical Properties of Bichi and Gaya Soil

Soil Parameter	Bichi	Gaya
BD g/cm ³	1.66	1.46
Sand (%)	76.50%	75.30%
Silt (%)	14.78%	15.10%
Clay (%)	8.72%	9.6%
Textural class	loamy sand	loamy sand

BD = Bulk Density

Table 2: Chemical Properties of Bichi and Gaya Soil

Soil parameter	Bichi	Gaya
pH (1:1)	6.72	6.37
EC (dSm ⁻¹)	0.04	0.01
Nitrogen (%)	0.05	0.04
Organic C (%)	0.54	0.34
Organic M (%)	0.94	0.58
P (mgkg ⁻¹)	7.48	13.91
Na (cmolkg ⁻¹)	0.03	0.03
Ca (cmolkg ⁻¹)	1.55	2.01
Mg (cmolkg ⁻¹)	0.78	0.80
EB.	2.52	3.05
CEC.	3.50	3.05

EC = Exchangeable Acidity, P = Phosphorus, Na = Sodium, CEC = Cation Exchange Capacity

Physical Properties of the Soils

- **Soil Texture**

The results in Table 1 revealed that both soils are loamy sand in texture. The soils are classified as loamy sand due to their specific proportions of sand, silt, and clay, which result from natural soil formation processes and parent material. These findings are consistent with multiple research studies that have demonstrated the agronomic advantages of loamy soils, including good drainage, aeration and fertility. Research on crop cultivation (e.g., *Stevia rebaudiana*) demonstrates that sandy loam soils maintain higher organic matter, nitrogen, potassium, and a more abundant beneficial microbiome compared to clay soils, resulting in better crop growth and biomass (Xinjuan *et al.*, 2024). For instance, research by Brandy and Weil (2016) highlights that loamy soils provide an optimal environment for root growth due to their favorable physical and chemical properties. The significance of having a balanced soil texture cannot be overstated when it comes to the sustainability of crop production. Proper soil texture facilitates optimal root development, water retention, and nutrient availability, all of which are essential for healthy plant growth (Smith *et al.*, 2020).

- **Bulk Density**

In Table 1, Bichi showing a higher bulk density (1.66 g/cm^3) than Gaya (1.46 g/cm^3), indicates a more compact soil structure in Bichi, characterized by a lower volume of pore space among its particles. Bulk density is inversely related to soil porosity, with higher bulk density values reflecting greater soil compaction and reduced pore space. This relationship negatively impacts root growth, water infiltration, and aeration (Tanveera *et al.*, 2015).

Chemical Properties of the Soils

- **Soil pH**

In Table 2, the soil pH values for Bichi (6.72) and Gaya (6.37) both fall within the slightly acidic range. According to standard classifications, a pH of 6.1 to 6.5 is considered slightly acidic, while a pH of 6.6 to 7.3 is neutral. Therefore, Bichi's soil pH of 6.72 is closer to neutral, whereas Gaya's soil pH of 6.37 is slightly acidic. The Bichi soil is ideal for most crops like groundnut, maize etc., because this pH level provides a balanced nutrient availability and supports active soil microbial processes, minimizing the need for soil amendments. This is because soil pH around 6.5 to 7.0 is close to neutral, which is optimal for nutrient uptake and microbial activity essential for healthy crop growth (Siobhan, 2022). Additionally, (Mabel *et al.*, 2016) notes that the optimum pH range for most soil activities, including effective bacterial functioning and nutrient bioavailability, is about 5.5 to 7.0, with a pH near 6.7 being ideal for balanced nutrient availability and microbial activity. Slightly acidic pH is generally favorable for most crops, but Gaya's lower pH may start to restrict some nutrient uptake, especially phosphorus (Brady and Weil, 2010).

- **Electrical Conductivity (EC)**

In Table 2, the electrical conductivity readings for Bichi and Gaya are 0.04 ds/m and 0.01 ds/m, respectively; both locations are classified as non-saline. Low EC values, such as 0.04 and 0.01 ds/m, classifying soils as non-saline, indicate minimal soluble salt presence, typical of leached, weathered tropical soils with low fertility (Okoror & Amanze, 2024).

- **Total Nitrogen**

In Table 2, the overall nitrogen concentration in the soil of Bichi at 0.05% is marginally greater than that of Gaya at 0.04%, although both figures are considered low, indicating limited nitrogen availability in these soils. (Aminu *et al.*, 2019; Abba *et al.*, 2024) which reported similar nitrogen contents for Bichi and Gaya soils, with Bichi slightly higher at 0.05-0.06 mg/kg than Gaya at 0.04 mg/kg. The low nitrogen levels suggest the need for nitrogen supplementation to improve soil fertility and crop productivity in these areas.

- **Organic Carbon and Organic Matter**

In Table 2, the organic carbon and organic matter contents measured in Bichi (0.54% OC; 0.94% OM) and Gaya (0.34% OC; 0.58% OM) soil indicate relatively low levels of soil organic material. These values fall below the generally accepted thresholds for optimal soil fertility, as soils with organic carbon content below 0.7% are typically classified as low in organic carbon (Brady & Weil, 2016). Low organic matter content negatively impacts soil structure, nutrient availability, and microbial activity, which in turn limits agricultural productivity. Organic matter improves soil structure by helping soil particles bind into stable aggregates, enhancing water infiltration and retention, and reducing surface crusting. This occurs because organic matter stimulates microbial activity that produces binding agents, leading to more stable soil aggregates, increasing soil porosity, and allowing better water movement and storage. (Franzluebbers, 2002; Bronick & Lai, 2005) show that soils with higher organic carbon content have significantly

improved infiltration rates and water-holding capacity and reduced surface crusting, especially under conservation practices like no-tillage that preserve organic residues on the surface. Low organic matter leads to poorer soil aggregation, reduced nutrient supply, and diminished microbial diversity, all of which constrain crop yields. Studies show that increasing soil organic matter can significantly boost crop yields; for example, there is about a 12% yield increase in organic matter in some soils (Jun *et al.*, 2022).

- **Available Phosphorus**

In Table 2, the significantly higher available phosphorus (P) in Gaya (13.9) compared to Bichi soil (7.48) can be related to several factors influencing phosphorus availability. Clay content and the presence of Fe^{3+} and Al^{3+} minerals in soil influence P adsorption and retention. Soils with higher clay and Fe/Al oxides can fix more P, reducing availability (Abdulkadir *et al.*, 2022). Bichi soil, described as sandy loam/clay loam with poor physical conditions, may have higher P fixation or lower organic matter, lowering available (Abdulkadir *et al.*, 2022). Exchangeable cation sodium (Na) value of 0.03 meq/100g soil at Bichi and Gaya locations indicates a very low level of sodium on the soil cation exchange sites. Similar studies on soil exchangeable sodium emphasize that low sodium levels (well below 1 meq/100g) do not pose sodicity problems and maintain good soil physical and chemical properties (Saka *et al.*, 2024).

- **Calcium**

In Table 2, the calcium content of 2.01 cmol/kg in Gaya soil compared to 1.55 cmol/kg in Bichi soil suggests that Gaya soil has a higher availability of calcium, which is crucial for soil and plant health. Recent research shows calcium's role in promoting soil organic carbon persistence by mediating interactions between organic matter, minerals, and microbes. Calcium enhances microbial activity that transforms plant litter into stable organic matter, improving soil fertility and carbon sequestration (Shabtai *et al.*, 2023). This suggests that higher calcium in Gaya soil could contribute to greater soil organic matter stability compared to Bichi.

- **Magnesium**

In Table 2, magnesium (Mg) is slightly higher in Gaya (0.80) than in Bichi (0.78), and they are quite similar, indicating comparable magnesium availability in both soils. The slight difference observed, 0.80 and 0.78, is unlikely to cause major differences in plant growth or soil fertility, assuming other factors are constant. Both soils appear to have sufficient magnesium to support healthy plant development and metabolic functions. Magnesium also influences soil microbial activity and nutrient availability, which indirectly supports plant health (Nazir *et al.*, 2023).

- **Exchangeable Bases**

In Table 2, the exchangeable bases in Gaya soil (3.05 cmol/kg) are higher than in Bichi soil (2.52 cmol/kg), indicating that Gaya soil has a greater capacity to supply essential base cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+}) to plants. Exchangeable bases are crucial for soil fertility because they influence nutrient availability, soil pH buffering, and overall soil structure. (Valentine & Bernard 2018) have shown that land use and management practices significantly affect exchangeable bases. A study found that arable lands had significantly higher exchangeable bases and CEC compared to pasture and irrigated lands, highlighting the dynamic relationship between soil management and nutrient status (Aliyu *et al.*, 2024). Another study (Sauwa *et al.*, 2024) reported that fertilization, especially with organic amendments like cow dung, increased exchangeable bases and improved soil fertility.

- **Cation Exchange Capacity (CEC)**

In Table 2, the Cation Exchange Capacity (CEC) values of soils in Bichi (3.5 meq/100g) and Gaya (3.05 meq/100g) indicate relatively low CEC levels, which are typical of sandy soils with limited nutrient-holding capacity. The slightly higher CEC in Bichi suggests it may have a marginally better capacity to retain nutrients compared to Gaya, possibly due to differences in soil texture, organic matter content, or clay minerals. Studies report that sandy soils typically have low CEC because of their coarse texture and low organic matter, while soils with more clay or organic matter have higher CEC (Aliyu *et al.*, 2024).

Conclusion

The soils in Bichi and Gaya share a loamy sand texture and exhibit generally low fertility status, with slight but notable differences in chemical properties. Gaya soil illustrates higher calcium levels, greater available phosphorus, and more exchangeable bases, which are beneficial for plant nutrition and may enhance crop uptake efficiency. Conversely, Bichi soils, while slightly more compact, possess a higher cation exchange capacity (CEC), indicating a somewhat better potential for nutrient retention.

Both locations exhibit low levels of total nitrogen and organic matter, signaling a need for fertility enhancement through organic or inorganic amendments. These deficiencies can negatively affect the growth and yield of nitrogen-demanding crops such as maize and groundnut.

The implications of these findings are significant for agricultural productivity in the region. For instance, groundnut—a major legume crop in both areas—relies heavily on phosphorus for nodulation and pod development, suggesting that Gaya soils may be more favorable unless phosphorus is supplemented in Bichi. Maize and sorghum, being heavy feeders, would also perform better with integrated soil fertility management practices that improve nitrogen content and organic matter, especially in Bichi.

Overall, the results emphasize the need for location-specific soil fertility management strategies tailored to crop requirements. Enhancing soil nutrient status through sustainable practices was key to optimizing the productivity of key crops such as groundnut, maize, millet, and sorghum in the Bichi and Gaya agro-ecologies.

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