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ASSESSMENT OF THE PHYSICOCHEMICAL PROPERTIES OF SOILS IN WARWADE VILLAGE, DUTSE LOCAL GOVERNMENT AREA, JIGAWA STATE, NIGERIA

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ABSTRACT
Agricultural productivity depends largely on the physical and chemical properties of soil, which influence nutrient availability, water retention, root development, and crop productivity. This study assessed the physical and chemical properties of soil in Warwade Village, located in Dutse Local Government Area of Jigawa State, Nigeria. Four cultivated rice farms (Farm 1–Farm 4) were selected for the study. Composite soil samples were collected from four cultivated rice farms at depths of 0- 20 cm and 20- 40 cm using a geographical positioning system to record coordinates, and Locus Map (Version 4.29, Asamm Software) was used to delineate the map. Data were analysed using one-way analysis of variance (ANOVA) at the 5% significance level. The soil texture was characterized by sandy loam to loamy sand. Bulk density ranged from 1.61 to 1.65 Mg m $^{-3}$ across the four farms, with the highest value recorded in Farm 3 (1.65 Mg m $^{-3}$). Soil pH ranged from moderately acidic in Farms 1 and 2 (5.85–6.15) to slightly acidic (5.55- 5.60) in Farms 3 and 4. Organic carbon was highest in Farm 4 (0.80 g/kg) and showed significant variation from the values in the other farms. Exchangeable calcium was highest in Farm 4 and lowest in Farm 2, with significant differences observed. Electrical conductivity (0.02–0.16 dS m $^{-1}$), organic carbon (0.23–0.80 g kg $^{-1}$), total nitrogen (0.09–0.35 g kg $^{-1}$), available phosphorus (9.64–11.21 mg kg $^{-1}$), exchangeable sodium (0.03–0.07cmol (+) kg $^{-1}$) and exchangeable acidity (0.30–0.90 cmol(+) kg $^{-1}$) showing no significant differences ($P > 0.05$) and were generally low among the four farms. This suggests that management of soil fertility is required to improve soil productivity and sustain agricultural production in Warwade.

Keywords: Physicochemical properties, Rice farm, Soils, Warwade village

INTRODUCTION
Soil is a living natural resource made up of mineral particles, organic matter, water, air and various living organisms. These components work together to support plant growth, maintain ecosystem functions and sustain agricultural production. The productivity of farmland largely depends on its physical and chemical properties, which control the availability of nutrients, water storage, root growth and soil biological activities (Brandy & Weil, 2017). Physical and chemical characteristics are fundamental for sustainable soil management, environmental conservation and food security. (FAO, 2015). The physical properties of soil, including texture, structure, bulk density, porosity and aggregate stability, strongly influence water infiltration, aeration, drainage and root penetration. Soil texture, determined by the relative proportions of sand, silt and clay, is considered one of the most stable soil properties and governs many other soil functions. Sandy soils generally have high infiltration rates but low water and nutrient-holding capacities; clay-rich soils retain more water and nutrients but often show poor drainage and aeration. Bulk density reflects soil compaction and pore space available for root growth. Increased bulk density restricts root penetration, reduces infiltration,

and limits crop productivity, particularly in intensively cultivated and semi-arid environments (Priori et al., 2020; Oritsejafor et al., 2022; Sani & Abdulkadir, 2026; Sufiyanu & Abdullahi, 2026). Recent studies in West Africa have shown that continuous cultivation without adequate soil conservation leads to deterioration of soil physical quality and reduced agricultural productivity (Lahmar et al., 2012; Diop et al., 2022).

The chemical properties of soils largely determine their fertility status and capacity to support crop production (Bhatt et al., 2019; Nguemezi et al., 2020; Trigunasih et al., 2023). Soil reaction (pH) regulates nutrient solubility, microbial activity and cation exchange processes. Most crops perform within a slightly acidic to neutral pH range, while strongly acidic or alkaline soils may reduce nutrient availability and increase the risk of toxicity or nutrient deficiencies. Soil organic carbon enhances aggregate stability, nutrient cycling, water retention and microbial activity. In tropical and semi-arid regions, organic carbon is low due to rapid decomposition, limited biomass return and continuous cultivation, resulting in declining soil fertility and reduced crop yields (Soudi et al., 2020; Abdulkadir et al., 2021; Abdulraheem et al., 2022). Cation exchange capacity (CEC), exchangeable bases and available phosphorus are important for nutrient retention and soil fertility status.

Semi-arid regions of Sudan savanna are particularly prone to soil degradation because uneven rainfall, high temperatures, sparse vegetation and intensive agricultural activities characterize them. According to Macaulay (2014) and Sani et al. (2025), in northern Nigeria, continuous cultivation, overgrazing, deforestation and poor land management practices have enhanced the loss of soil nutrients, reduced soil organic matter and increased soil compaction and erosion. These processes damage soil structure, decrease water use efficiency, and ultimately reduce agricultural productivity. Sustainable agricultural production depends on clear knowledge of soil physicochemical properties, as these properties determine soil fertility, water availability, nutrient retention, and crop performance. In the Sudan savanna region of northern Nigeria, soils are increasingly affected by continuous cultivation, overgrazing, vegetation loss, erosion, and climate variability. These factors contribute to nutrient depletion, decline in soil organic matter, soil compaction and reduced productivity, making it difficult to maintain sustainable crop production. Warwade Village in Dutse Local Government Area of Jigawa State is an important agricultural community where farming is the main source of livelihood. However, there is limited scientific information on the physicochemical characteristics of the soils in the area. The absence of detailed basic information on soil properties hinders the reliable assessment of soil fertility and agricultural potential. As a result, farmers often depend on fertilizer recommendations and traditional management practices that may not be suitable for the local soil conditions. Without adequate knowledge of the soil's physical and chemical properties, it is difficult to identify soil fertility constraints, recommend appropriate soil management practices and develop effective land use planning. The outcomes of the study provide useful information on the fertility status and variability of the soils in the study area. The results will assist farmers in improving nutrient management, guide extension workers in making location-specific recommendations, and support policymakers, land managers, and researchers in future soil studies in developing sustainable soil management strategies that enhance agricultural productivity, conserve soil resources, and improve food security. Therefore, this study aimed to assess the physicochemical properties of the soils of Warwade Village, Dutse Local Government Area of Jigawa State, Nigeria.

MATERIALS AND METHODS

Study Area

The study was conducted in Warwade Village, Dutse Local Government Area of Jigawa State, Nigeria (Figure 1). The village lies within the Sudan Savanna agro-ecological zone of north-western

Nigeria and is characterized by a tropical semi-arid climate. The study area is located between 11°44′40″ and 11°45′18″ N and 9°12′45″ and 9°13′28″ E, approximately 15 km south of Dutse, the capital of Jigawa State. The climate is characterized by a distinct wet and dry season. The rainy season usually extends from May to September or early October, while the dry season lasts from October to April. Annual rainfall ranges from 600 to 1,000 mm, with an average of approximately 650–800 mm. Temperatures are generally high throughout the year, with minimum temperatures of 14–15°C during December and January and maximum temperatures of 40–43°C during March to May. The mean monthly temperature is about 35°C. The inhabitants are predominantly engaged in agriculture, including rain-fed and irrigated rice cultivation, livestock production, fishing, and other related farming activities.

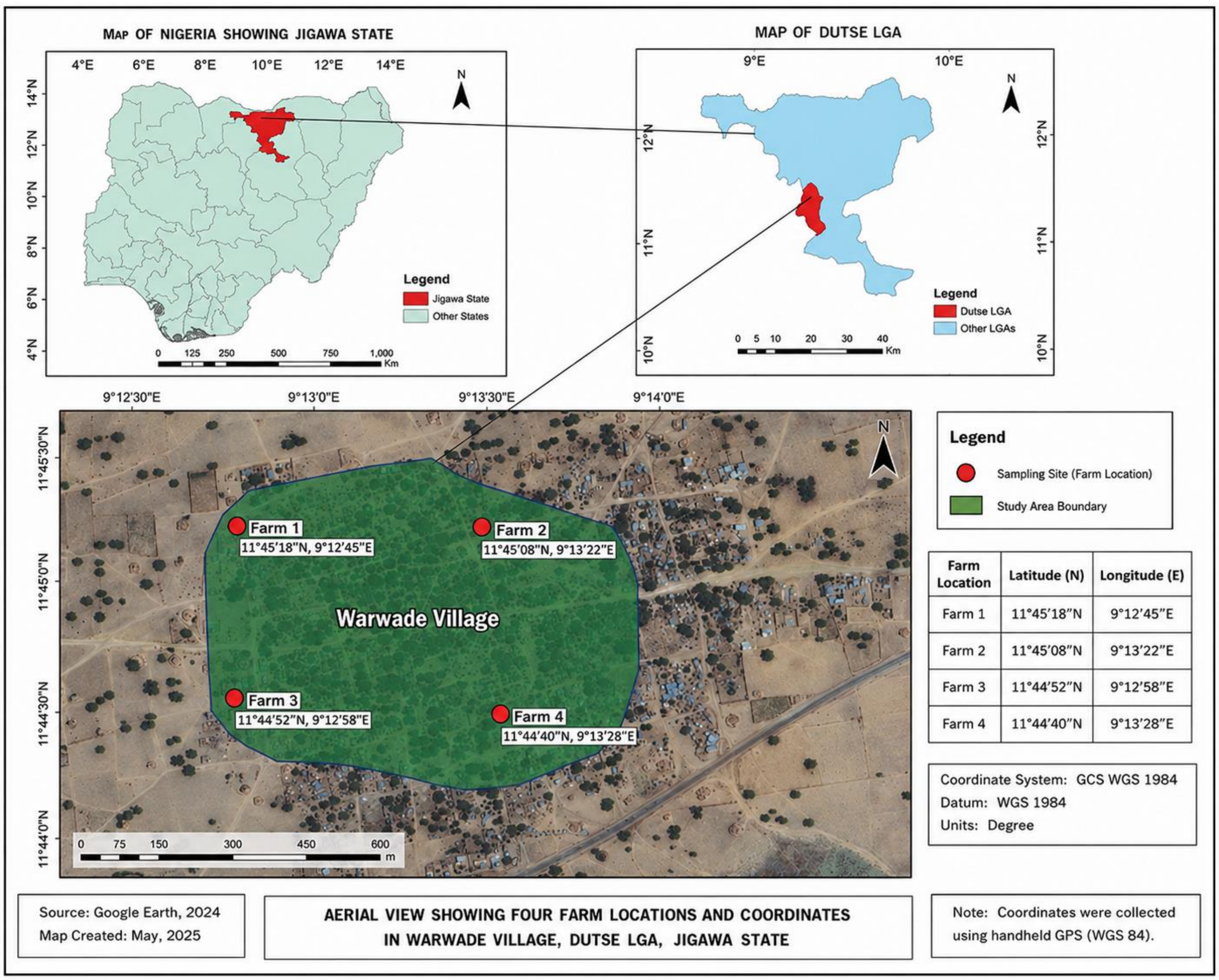

Figure 1: Location of the study area showing sampling sites

Field work

A field survey was carried out in four cultivated rice farms (Farm 1–Farm 4) located within Warwade Village (Figure 1). The geographical coordinates of each farm were recorded using a handheld Global Positioning System (GPS) based on the World Geodetic System (WGS 84) datum. At the same time, the boundaries of the study area were delineated using Locus Map software. Within each farm, a 0.5-ha representative sampling plot was randomly selected and demarcated. Soil samples were collected from two depths (0–15 cm and 15–30 cm) using a soil auger. At each sampling depth, ten replicate composite samples were collected. Each composite sample consisted of several soil cores collected randomly across the sampling plot in a zigzag pattern and thoroughly mixed to obtain a representative sample. The collected soil samples were placed in labelled polyethylene bags and transported to the laboratory for further processing and analysis.

Soil Sampling

Soil samples were collected from four cultivated rice farms (Farm 1–Farm 4) in Warwade Village. The geographical coordinates of each sampling location were recorded using a handheld Global Positioning System (GPS). At each farm, ten soil cores were randomly collected using a soil auger at two sampling depths (0–20 cm and 20–40 cm) following a zigzag sampling pattern. The ten soil cores collected at each depth were thoroughly mixed to form one representative composite sample for each farm. The composite samples were placed in labelled polyethylene bags and transported to the Soil Science Laboratory for analysis. In the laboratory, the samples were air-dried at room temperature, gently crushed with a wooden pestle and porcelain mortar, and passed through a < 2mm sieve to remove stones, plant residues and other coarse materials. The processed samples were stored in clean polyethylene bags prior to laboratory analysis.

Laboratory Analysis

Particle size distribution was determined by the Bouyoucos hydrometer method as described by Gee and Or (2002). Soil bulk density was determined using the core method according to Blake and Hartge (1986). Undisturbed soil samples were collected in the field using a cylindrical core sampler measuring 5 cm in diameter and 5 cm in height. Soil pH and electrical conductivity (EC) were determined in a 1:1 soil-to-water suspension using a calibrated pH meter and electrical conductivity meter following the procedure described by Wang et al. (2015). Soil organic carbon (SOC) was determined using the Walkley and Black wet oxidation method (Walkley & Black, 1934), while total nitrogen (TN) was determined using the micro-Kjeldahl method described by Bremner (1996). Available phosphorus (P) was extracted using the Bray I method (Bray & Kurtz, 1945).

Exchangeable calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) were extracted with 1 M ammonium acetate (NH_4OAc) at pH 7.0 following the procedure of Anderson and Ingram (1993). Calcium and magnesium concentrations were determined using an atomic absorption spectrophotometer (AAS), while potassium and sodium were measured using a flame photometer. Cation exchange capacity (CEC) was determined by the 1 M ammonium acetate method at pH 7.0 as described by Chapman (1965). Exchangeable acidity was determined using the method described by Anderson and Ingram (1993).

Statistical analysis

Statistical differences among land rice farms were analyzed by a one-way analysis of variance (ANOVA) at $p< 0.05$ significance levels. Least significant difference (LSD) was used to evaluate the differences within soil variables.

RESULTS AND DISCUSSION

The physicochemical properties of soils collected from the four rice farms are presented in Table 1. The soils at the four locations varied in texture from sandy loam at Farm 1 and Farm 3 to Loamy sand at Farm 2 and Farm 4. These results are similar to the findings of Santuraki et al. (2025), who stated that soils of Dutse are more sandy loam and loamy sand in nature. The sand content ranged from 72-78%, silt from 17-19%, and clay from 5-11%, respectively. The high sand content across the farms is attributed to the aeolian sandy parent material from which the soils developed. This parent material is characteristic of the Sudan Savanna region of northern Nigeria and commonly coarse-developed, textured soils with low nutrient- and water-holding capacities. A similar observation was mentioned by Raji et al. (2023), who confirmed that the predominance of sand materials from the Sudan savanna of Nigeria is likely due to their formation from aeolian sand deposits. There were no significant differences (P > 0.05) in sand, silt or clay contents among the farms. The bulk density values ranged from 1.61 Mg/m³ in Farm 1, 1.63 Mg/m³ in Farm 2, 1.65 Mg/m³ in Farm 3, and 1.63 Mg/m³ in Farm 4, respectively. Farm 3 recorded the highest bulk density (1.655 Mg m^{-3}), implying slightly greater soil compaction than the other farms. In contrast, Farm 1 had the lowest value (1.61 Mg m^{-3}) with no significant differences (P > 0.05) among the four farms (Table 1). The higher bulk density indicates that the soils possess similar physical characteristics throughout the study area.

Table 1: Physico-chemical properties of the soil of Warwade

Parameters	Farm 1	Farm 2	Farm 3	Farm 4
Sand (%)	74.0^{a}	76.0^{a}	72.0^{a}	78.0^{a}
Silt (%)	19.0^{a}	17.0^{a}	17.0^{a}	17.0
Clay (%)	7.0^{a}	7.0^{a}	11.0^{a}	5.0^{a}
Textural class	SL	LS	SL	LS
Bulk density (Mg/m³)	1.61^{a}	1.63^{a}	1.65^{a}	1.63^{a}
pH (H_2^{O})	6.15^{a}	5.85^{a}	5.60^{a}	5.55^{a}
EC (dS/m)	0.03^{a}	0.03^{a}	0.02^{a}	0.16^{a}
Organic carbon (g/kg)	0.23^{a}	0.42^{a}	0.40^{a}	0.80^{a}
Total nitrogen (g/kg)	0.12^{a}	0.09^{a}	0.23^{a}	0.35^{a}
Organic matter (g/kg)	0.40^{a}	0.72^{a}	0.68^{a}	1.38^{b}
Available P (mg kg ^{1})	9.64^{a}	9.96^{a}	10.36^{a}	11.21^{a}
CEC (Cmol/kg)	4.53^{a}	2.26^{b}	4.46^{a}	4.50^{a}
Ca (Cmol/kg)	2.40^{ab}	1.22^{b}	2.25^{ab}	2.67^{a}
Mg (Cmol/kg)	1.12^{ab}	0.57^{b}	1.17^{ab}	1.24^{a}
K (Cmol/kg)	0.07^{c}	0.12^{b}	0.16^{a}	0.11^{b}
Na(Cmol/kg)	0.03^{a}	0.05^{a}	0.07^{a}	0.07^{a}
EA (Cmol/kg	0.90^{a}	0.30^{a}	0.55^{a}	0.40^{a}

Means followed by the same letter are not significantly different at p<0.05 using LSD Test.

The soil pH values ranged from 6.15 (Farm 1), 5.85 (Farm 2), 5.60 (Farm 3), and 5.55 (Farm 4), reflecting that the soils were slightly and moderately acidic. Farm 1 had the highest pH (6.15), whereas Farm 4 had the lowest (5.55). The observed soil pH range is consistent with previous studies by Umar et al. (2023), Gambo et al. (2025), and Santuraki et al. 2025), who reported that the soils in Dutse vary from slightly acidic to moderately acidic and strongly alkaline. Though the variation among the farms was not statistically significant (P > 0.05), the slight variation in soil pH may be attributed to differences in organic matter decomposition, leaching of basic cations and fertilizer application. The soil pH values are within the optimum range for rice cultivation. The electrical conductivity values were (0.03dS/m) Farm 1and 2, (0.02 dS/m) for Farm 3 and (0.16 dS/m) for Farm 4, respectively. The higher EC observed in Farm 4 (0.160 dS/m) compared with the other farms may be attributed to a higher concentration of soluble salts in the soil solution. This could result from the accumulation of basic cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) released during the decomposition of organic residues and mineral weathering. In addition, differences in periodic deposition of dissolved salts through runoff may contribute to salt accumulation in Farm 4. However, the EC value remains well below the salinity threshold of 4 dS/m, indicating that the soil is non-saline and suitable for crop production (Hazelton & Murphy, 2016).

Cation Exchange Capacity levels of the soil varied significantly (P<0.05) in the four locations. The significantly lower cation exchange capacity (CEC) found in Farm 2 (2.26 cmol(+) kg^{-1}) compared with the other farms (4.46–4.53 cmol(+) kg^{-1}) may be attributed to the predominance of coarse-textured soil, low amount of clay minerals and the low reserve of exchangeable base cations, particularly calcium and magnesium. Also, under moderately acidic conditions, pH-dependent charges on soil organic matter and clay minerals are reduced, leading to a decline in CEC. These findings are in agreement with those of Bortoluzzi et al. (2006), who stated that CEC in sandy soils is strongly influenced by pH-dependent charges, clay content and organic matter. Similarly, Fidalski et al. (2020) observed that the inherently low clay and organic matter contents of tropical sandy soils are the primary factors responsible for their low cation exchange capacity.

Organic carbon contents were low across all the farms, with Farm 4 showing higher values (1.38-0.80 g/kg), whereas Farm 2, 3 and 4 had values of (0.23 g kg^{-1}, 0.42 g kg^{-1} and 0.40 g kg^{-1}). The higher organic carbon content recorded in Farm 4 (0.805 g kg^{-1}) may be due to the remaining crop residues on the farm, litter fall, root biomass and, where applicable, organic amendments such as animal manure. These materials contribute carbon to the soil during decomposition, thereby increasing soil organic carbon contents. The findings of this study agree with those of Feng et al. (2022) and Liu et al. (2024), who reported that crop residues, litter deposition, root biomass, and organic manure contribute to increased soil organic carbon contents. Organic matter content was significantly different ($P < 0.05$) among the farms, with Farm 4 having the highest value (1.380 g kg^{-1}). This may be a result of residue management, cropping history, and cultivation practices among the farms, which may also have contributed to the observed variation. Lal (2020) stated that higher soil organic matter enhances nutrient retention, soil structure and biological activity, thereby improving overall soil quality. Total nitrogen content showed no significant variation ($P > 0.05$) across the four farms; however, Farm 4 was found to have the highest value (0.355 g kg^{-1}), while the lowest value (0.098 g kg^{-1}) was observed in Farm 2. The low total nitrogen contents observed in the study may be linked with the low organic matter content of the soils. In the Sudan Savanna of West Africa, soils are inherently low in soil organic carbon because of limited organic matter and rapid decomposition under high temperatures. These conditions restrict the accumulation and cycling of nitrogen (Botiono et al., 2018).

The available phosphorus content ranged from 9.64 to 11.21 mg kg ^{1} across the four farms. Farm 4 had the highest value (11.21 mg kg ^{1}), Farm 3 (10.36 mg kg ^{1}), Farm 2 (9.96 mg kg ^{1}), while Farm 1 had the lowest (9.64 mg kg^{-1}). These values indicate low to moderate phosphorus availability, which is common in sandy soils in the Sudan Savanna of northern Nigeria. The higher available phosphorus in Farm 4 may be attributed to organic matter accumulation, previous phosphorus fertilizer application or the mineralization of organic residues. Organic matter decomposition releases phosphate ions into the soil solution while organic compounds reduce phosphorus fixation by iron and aluminum oxides, thereby increasing phosphorus availability (Botiono et al., 2018).

Exchangeable calcium showed significant variation ($p < 0.05$) among the four farms. The highest calcium content was recorded in Farm 4 (2.676 cmol(+) kg^{-1}), Farm 1 (2.405 cmol(+) kg^{-1}) and Farm 3 (2.251 cmol(+) kg^{-1}), whereas the lowest value was observed in Farm 2 (1.223 cmol(+) kg^{-1}). Farm 4 was significantly higher than Farm 2, while Farms 1 and 3 did not differ significantly from either Farm 4 or Farm 2. A higher value was found in Farm 4, indicating the residual effects of fertilizer or manure application, and the weathering of calcium-bearing minerals may have contributed to the higher calcium concentration. Calcium is an essential macronutrient that promotes root development, cell wall formation, membrane stability and nutrient uptake, making it vital for plant growth and soil structural stability (Brady & Weil, 2017).

Exchangeable magnesium varied significantly ($P < 0.05$) across all the farms. Farm 4 had the highest exchangeable magnesium content (1.249 cmol(+) kg^{-1}), Farm 3 (1.174 cmol(+) kg^{-1}) and Farm 1 (1.124 cmol(+) kg^{-1}) and (0.571 cmol(+) kg^{-1}) recorded the lowest. Magnesium is an essential macronutrient that forms the central atom of the chlorophyll molecule and plays important roles in photosynthesis, enzyme activation, carbohydrate metabolism, and energy transfer. Therefore, adequate magnesium levels are necessary for optimum crop growth and productivity (Brady & Weil, 2017; Marschner, 2012). Exchangeable potassium differed significantly ($p < 0.05$) among all the farms. The highest potassium content was found in Farm 3 (0.160 cmol (+) kg^{-1}), Farm 2 (0.120 cmol(+) kg^{-1}) and Farm 4 (0.110 cmol(+) kg^{-1}), while the lowest value was observed in Farm 1 (0.075 cmol(+) kg^{-1}). Low potassium content in Farm 1 may be due to continuous crop removal, limited potassium replenishment, and the predominance of sandy soil particles, which possess low nutrient-retention capacity. Potassium is an essential macronutrient that regulates enzyme activation, photosynthesis, protein synthesis, osmotic regulation, and stomata function, thereby enhancing crop growth and tolerance to environmental stress (Brandy & Weil, 2017). Exchangeable sodium showed no significant variation ($P > 0.05$) across the four farms. The sodium values ranged from (0.03 cmol(+) kg^{-1}) in Farm 1 to (0.070 cmol(+) kg^{-1}) in Farms 3 and 4, with Farm 2 having the lowest (0.05 cmol(+) kg^{-1}). Farms 3 and 4 had slightly higher sodium concentrations. The low sodium value is optimal for plants because excessive exchangeable sodium can reduce soil aggregation, decrease water infiltration, and impair crop growth. Exchangeable acidity showed no significant variation ($P > 0.05$) across the four farms. The values ranged from 0.30 cmol (+) kg^{-1} in Farm 2 to 0.90 cmol(+) kg^{-1} in Farm 1, while Farms 3 and 4 recorded intermediate values of 0.55 and 0.40 cmol(+) kg^{-1}, respectively. Higher exchangeable acidity in Farm 1 may reflect differences in the proportion of exchangeable hydrogen and aluminum ions on the soil exchange complex.

CONCLUSION AND RECOMMENDATIONS

The study showed that the soils of Warwade Village, Dutse Local Government Area, are predominantly sandy loam and loamy sand, indicating their development from sandy parent materials characteristic of the Sudan Savanna. Soil texture, bulk density, pH, electrical conductivity, total nitrogen, exchangeable sodium, and exchangeable acidity did not show significant variation among the four farms; significant variations were observed in organic carbon, organic matter, available phosphorus, exchangeable calcium, magnesium, potassium, and cation exchange capacity. Farm 4 generally had a better fertility status, indicating better nutrient status than the other farms. The soils were generally characterized by low organic matter, low total nitrogen, and low cation exchange capacity, confirming their inherently low fertility and limited nutrient-retention capacity. These conditions are largely attributable to the coarse-textured nature of the soils and the semi-arid environment. The results provide valuable new information on the physicochemical properties and fertility status of the soils in the study area. There is a need for appropriate use of organic amendments, fertilizer application, residue retention, and routine soil testing to improve soil quality, enhance nutrient availability, and promote sustainable agricultural productivity in Warwade Village.

The study therefore recommended that proper and adequate application of both organic and inorganic fertilizers should be practiced, which will improve the nutrient supplying capacity of the soil to enhance the productive capacity. The farmers should engage in green manuring on their farms, which can help stabilize the soil as well as increase the nutrient status of the soil.

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