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SOIL NUTRIENT ANALYSIS FOR RICE PRODUCTIVITY IN GWAGWALADA AREA COUNCIL OF THE FEDERAL CAPITAL TERRITORY, ABUJA, NIGERIA

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Abstract

This study examined the soil nutrient analysis for rice productivity in Gwagwalada. It aimed to analyze the nutrient composition within the rice farms, determine variations across different sites, and compare these values with the Food and Agriculture Organization (FAO) standards for rice cultivation. A total of sixteen (16) soil samples were collected from four (4) sites, with four (4) samples per site. These samples were composited into one (1) representative sample per site, totaling four (4) samples, which were analyzed using standard laboratory procedures. Data analysis employed descriptive statistics and Analysis of Variance (ANOVA) to determine variations across sites and compare them with FAO standards. Findings revealed site-specific variations in soil properties. Nitrogen levels ranged from 90–150 kg/ha across the sites, while phosphorus ranged from 15–40 kg/ha. Potassium concentrations, the highest among all parameters, varied from 135–280 g/kg, exceeding FAO standards across all sites. Soil pH levels ranged between 5.5–7.2, with Site D recording a slightly higher-than-recommended pH. Organic matter content was relatively low across the sites, ranging from 1.6% to 3.6%, indicating potential limitations in long-term soil fertility and sustainability. The ANOVA results showed significant variations in soil parameters across the sites (F = 0.335), while comparisons with FAO standards (F = 0.323) indicated that the deviations, though present, were not highly significant. The study concludes that variations in soil colour and structure influence soil properties, with potassium consistently recording the highest mean values, whereas organic matter remained the lowest. The low organic matter content suggests limited soil organic carbon, which could affect microbial activity, water retention, and overall soil sustainability. Based on these findings, the study recommends adopting soil conservation techniques such as terracing and mulching to maintain soil structure and water retention. The application of organic amendments like compost and farmyard manure, alongside controlled use of inorganic fertilizers, is crucial for sustaining soil fertility. Regular soil testing should be conducted to manage pH variations effectively, ensuring optimal nutrient availability. Additionally, strengthening agricultural extension services will enhance farmers' knowledge of soil conservation and sustainable rice production practices in Gwagwalada.

Keywords: *Soil-pH, Soil-nutrient, Soil-conservation, Rice-yield, Rice-farm*

Introduction

Rice yield is susceptible to soil deterioration from erosion, nitrogen depletion, and salinization, particularly in areas that rely on rain-fed and irrigated systems (Lal, 2014). A well-known staple in Africa that makes up a significant amount of the typical household diet is rice (Achichi *et al.*, 2023). Soil conservation is crucial for enhancing the sustainability and productivity of rice cultivation (Lal, 2014). Soil conservation is crucial for enhancing the sustainability and productivity of rice cultivation (Lal, 2014).

Onyegbula and Oladeji (2017) confirmed that environmental factors - the most significant of the several elements influencing agricultural output - have a significant impact on rice productivity. Degradation of soil is a major worldwide issue that threatens environmental sustainability and all aspects of human progress, making it a pressing political and social issue.

According to Daramola and Aina (2019), rice is a crop that needs a lot of nitrogen, phosphate, and potassium to provide the best results. Unsustainable farming practices—such as continuous cultivation without fallow seasons or the use of chemical fertilizers without replacing organic matter—have contributed to serious soil deterioration. Land degradation brought on by unsustainable farming methods is one of the elements causing this shortfall. The combined consequences of overcultivation, poor irrigation management, and soil erosion have reduced the productivity of rice production in places like Gwagwalada.

Numerous researchers have reported the advantages of soil conservation for agricultural output. Brady and Weil (2016) assert that a number of variables, such as the amount of organic matter present, the availability of nutrients (such as potassium, phosphorus, and nitrogen), the pH of the soil, and biological activity, all affect soil fertility. Rice (*Oryza sativa*) has specific nutrient requirements that significantly affect its growth and yield, a combination of macro-nutrients, including nitrogen (N), phosphorus (P), and potassium (K), along with micronutrients such as zinc (Zn) and iron (Fe); nitrogen is particularly critical for rice yield, as it promotes vegetative growth and contributes to grain filling (Wang *et al.*, 2019 and Areo, 2023). Research by Opara-Nadi (2007) emphasizes that the availability of these nutrients in the soil directly correlates with rice yield potential. Mohammed *et al*. (2019) investigated Nigeria's rice yield possibilities and difficulties. In Dobi, Gwagwalada Area Council, Federal Capital Territory, Nigeria, Aondoakaa and Agbakwuru (2012) evaluated the land's potential for rice farming. Jegede *et al*. (2021) examined the connection between the socioeconomic traits of rice farmers and soil management techniques.

However, despite these discoveries, not much has filled the study gap on specific rice farm nutrient analysis. This study examines the soil nutrient analysis for rice productivity in Gwagwalada rice farms, with the aim of determining the variations across farm lands; and comparing these values with the Food and Agriculture Organization (FAO) standards for rice cultivation.

The specific objectives set for the study include: analyzing the nitrogen, phosphorus, potassium, pH and organic matter contents within the rice farm in the study area; determining the variations in mentioned soil nutrient; comparing the levels of nitrogen, phosphorus, potassium, pH and organic matter content of rice farm with the Food and Agriculture Organization (FAO) Standard and finally; evaluating best soil management techniques for enhancing rice yield in the study area.

Study Area

Gwagwalada is situated along Abuja-Lokoja road at about 55 Km away from FCT and centrally located between latitudes 8^o 55'N and 9^o 00'N and longitudes 7^o 00'E and 7^o 04'E, with a population of about 157,770 at the 2006 census, the region covers a total landmass of 1,043 km^2 out of the 8,000 km^2 of the total FCT land mass and located at the center of very fertile area with abundance of grasses (Ishaya, 2013). The area is bordered by Kuje Area Council to the East, Abaji area Council to the West, Kwali area council to the south and Abuja municipal to the Northeast and to the North by Suleja local government area of Niger state (Balogun, 2001, cited in Areo, 2021).

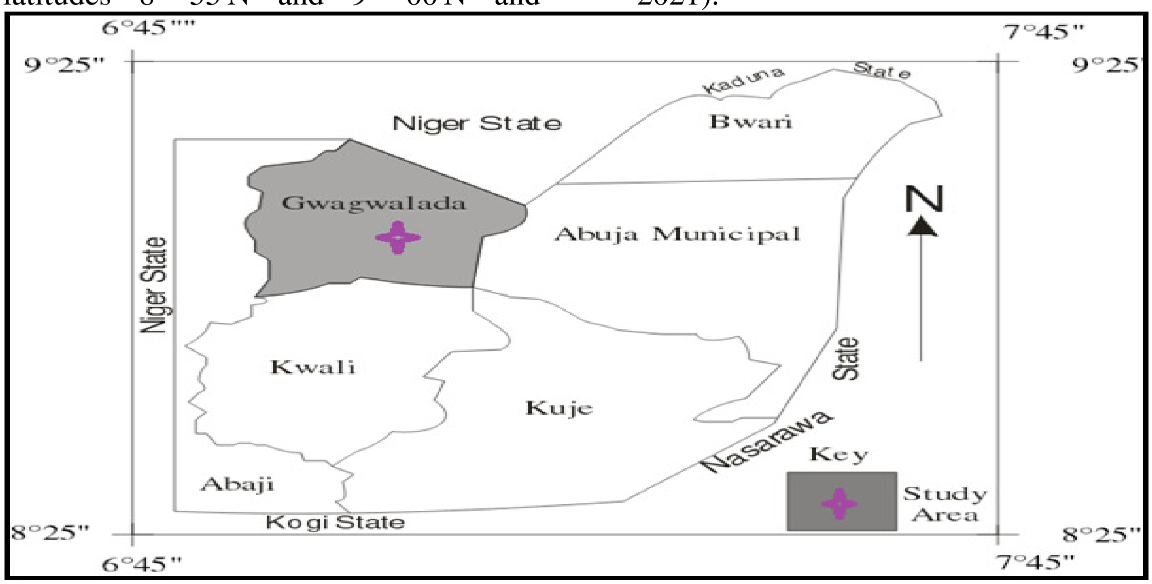

Fig. 1: Administrative Map of Gwagwalada Area Council.
Source: Uniabuja GIS Lab., 2024.

The type of rocks found in Gwagwalada include metamorphic and igneous rocks, generally, the rocks are highly sheared. Also, the types of soil in Gwagwalada are generally shallow and sandy in nature. The high sand content particularly makes the soil to be highly erodible (Areo, 2023). The tree species found there include *Terminalia macroptera*, *Terminalia laxiflora*, *Afromosis laxiflora*, *Anonas senegalesis*, and *Pilioostigma thonningii* (Areo, 2021).

According to Ishaya *et al*. (2016), it contains African locust bean (*Parkia biglobosia*), *Albizia* sp., *Daniela oliveri*, *Butyrospermus paradoxum*, and are among the tree species identified. In this setting, the most common tree is the shea butter tree (*Butyrospermus paradoxium*) (Areo, 2023).

Table 1: Soil Samples Locations in the Study Area

S/N	Soil Samples	Location	Coordinates
1	A	Site A	8°.95'03"N, 7°.43'00"'E 8°.97'05"N, 7°.33'01"'E 8°.98'08"N, 7°.41'00"'E 8°.96'07"N, 7°.33'11"'E
2	B	Site B	8°.94'47"N, 7°.26'17"'E 8°.94'43"N, 7°.35'14"'E 8°.93'45"N, 7°.33'23"'E 8°.97'44"N, 7°.36'15"'E
3	C	Site C	8°.96'38"N, 7°.44'26"'E 8°.98'25"N, 7°.44'23"'E 8°.95'23"N, 7°.47'27"'E 8°.97'34"N, 7°.48'22"'E
4	D	Site D (Control Site)	8°.98'36"N, 7°.45'25"'E 8°.98'31"N, 7°.44'25"'E 8°.98'43"N, 7°.46'28"'E 8°.97'44"N, 7°.47'23"'E

Materials and Methods

The study adopted a Cross-Sectional Research Design. A cross-sectional study design is suitable for assessment of the soil properties at the specific point of different land uses. This design is chosen because it allows for the collection of data from multiple sampling points within the selected unit.

The primary data was sourced via direct observations, use of Global Positioning System (GPS) for taking coordinates of the soil sample site and photos of selected sites. Academic journals, research papers, and conference proceedings and maps were good sources of secondary data used in this study. The instruments required for the study and their uses are presented in the Table 2.

Table 2 Instruments Required for the Study

S/N	Instruments	Model	Uses
1	Soil auger	Agricultural Measurement Solutions (AMS) Regular Soil Auger brand.	The soil auger is used to bore holes in soil. It is also used to take samples from the required depths.
2	Global Positioning System (GPS)	GARMIN III model	Used for picking coordinates of selected sites.
3	Spectrophotometer	Thermo Fisher Scientific, thermo Scientific GENESIS series.	The spectrophotometer is used to measure the concentration of nutrients such as nitrogen, phosphorus, and potassium in the sampled soil.
4	Soil thermometer	REOTEMP Soil Thermometer model with 8-inch Probe.	The soil thermometer is used to measure the temperature of the soil, which is an important factor

			that affects the biological activity in the soil.
5	Glassware and chemicals	Kimble Chase brands.	Glassware such as beakers, pipettes, and test tubes, and chemicals such as reagents for nutrient analysis are used for the analysis.
6	Oven	Whirlpool, single and double wall ovens.	The oven is used for drying the soil samples before analysis.
7	Weighing balance	The Mettler Toledo Precision Balance.	The weighing balance is used for weighing soil sampled and reagents.
8	Notebook and pen	Moleskine high-quality notebook and pen.	A notebook and pen are needed for recording the measurements, results and observations during the analysis.
9	Masking tape	Paper type	For labeling of soil samples
10	Gloves and lab coats	Ansell latex hand gloves and fabric lab coat.	Gloves and lab coats are used to protect the researcher from harmful chemicals during the analysis.
11	Trowel and shovel	Iron and steel brands.	They are used to collect shallow soil samples, up to a depth of about 6 inches.
12	Soil probe	The Oakfield T-100 Soil Probe.	Soil probe is useful in this study for taking samples from a specific location in the field.
13	Piston sampler	AMS Piston Soil Probe.	It is a tool used to collect undisturbed soil samples for the study. The sampler consists of a hollow tube that is pushed into the soil using a hydraulic ram.
14	Measuring tape	Steel tape	It is used to measure distance

After visiting and observing the study area, the following sites were selected: site A, site B, site C and D. Soil sampling was carried out on the site with layers ranging from 0-15cm and 15-30cm using a soil auger. Sixteen (16) soil samples were collected from the four (4) sites. Four (4) soil samples per site. The four (4) soil samples from each site were mixed together to form one (1) for each site, totaling four (4) samples. These samples were prepared, labelled and taken to laboratory for analysis.

Plate 1: Google Imagery Showing Sampling Points

Soil auger was used to collect samples at depths of 0-15cm and 15-30cm to capture the soil profile's variability each for site A, site B, site C and D within the study area. Sub-samples from each location were collected and mixed together to form a composite sample representative of the study area. All visible plant residues, stones, roots, and large debris from the soil sample were removed using hand gloves. Larger clumps of soil were broken down to ensure homogeneity. The soil samples were allowed to air-dry in a well-ventilated area away from direct sunlight. The samples were turned periodically to ensure even drying. The samples were dried until they reached a constant weight, indicating that all moisture has evaporated. The soil samples were broken down into smaller particles to ensure uniformity and passed through a sieve with a mesh size of 2mm to remove large aggregates and stones. The sieved soils were collected in a clean container. The prepared soil samples were labeled in airtight containers. The prepared samples were stored in a cool, dry place to prevent moisture absorption and microbial activity before transporting to the laboratory for soil tests.

The null hypotheses formulated for the study were tested using one-way analysis of variance (ANOVA) to find out if there is a significant variation between the soil properties for site A, site B, site C and D within the study area. The one-way analysis of variance (ANOVA) is preferred in this study because it is a statistical method for comparing the means of three or more independent groups to see if there are statistically significant differences between them. When assessing differences in soil characteristics between various sites, or land uses it is very helpful in soil research. This analysis aids in determining if variations in these characteristics are noteworthy among the different sample locations within the study site. For statistically different parameters at probability 5% ($p \leq 0.05$).

The data obtained were computed and presented using tables. Tables were used to make the analysis easy to interpret. The tables show the F-ratio, p-value, sample size for each group, degrees of freedom (df), sum of squares (SS), mean square (MS), and source of variance.

Results and Discussion

Soil Properties from the Selected Sites in the Study Area

Table 3 shows the results of soil parameters at Site A in the study area. The table shows that the soil color at Site A is light brown with crumb structure. The soil nitrogen content ranges from 108-135 kg/ha with mean value of 121.5. The soil phosphorus content ranges from 15-31 kg/ha with mean value of 23.0. The soil potassium content ranges from 150-271 g/kg with mean value of 210.5. The soil pH content ranges from 5.5-7.0 with mean value of 6.25. While the organic matter content is 2.8%. The study revealed that the highest (210.5) mean value was recorded in potassium content at Site A, while the soil organic matter recorded the least (2.8) mean value at Site A. These findings align with those of Brady and Weil (2019) and Areo 2023, nitrogen is an essential nutrient for plant development and is crucial for the production of chlorophyll and photosynthesis. The measured values show adequate nitrogen levels to sustain crop yield, falling within the moderate fertility range. On the other hand, continued cropping or subpar management techniques may cause nitrogen depletion (Lal, 2020). Plant energy transmission and root growth depend on phosphorus (Marschner, 2012). Although the lower end of the range (15 kg/ha) could not be sufficient for phosphorus-demanding crops, the reported values are in line with the critical threshold for many crops in tropical soils, potentially restricting yields in some regions (McDowell and Condron, 2020). According to Mengel and Kirkby (2012), potassium controls water absorption and increases plant resilience to disease. In Site A, which had the highest mean value (210.5 g/kg), the elevated potassium levels suggest ideal circumstances for crop resilience and productivity. The mean pH of the soil was 6.25, with a range of 5.5 to 7.0, suggesting slightly acidic to neutral conditions. For the majority of crops, this range is optimal because it makes vital nutrients more accessible. 2.8% organic matter was present, which is less than the 3–5% suggested for the best soil fertility (FAO, 2017). Enhancing soil structure, water retention, and nutrient cycling all depend heavily on organic matter (Stockmann, 2013). Unless organic inputs, such compost or manure, are incorporated into the soil management plan, the low organic matter level seen at Site A raises the possibility of difficulties sustaining long-term soil fertility.

Table 3: Soil Parameters of Site A in the Study Area

S/N	Soil parameters	Sample A (kg/ha)	Mean ± SD
1	Soil colour	Light brown	-
2	Soil structure	Crumb Structure	-
3	Nitrogen	108 – 135	121.5 ± 7.79
4	Phosphorus	15 – 31	23 ± 4.62
5	Potassium	150 – 271	210.5 ± 35.02
6	pH	5.5 – 7.0	6.25 ± 043
7	Organic Matter	2.8%	2.8 ± 0

Table 4 shows the results of soil parameters at Site B in the study area. The table shows that the soil color at Site B is dark gray with granular structure. The soil nitrogen content ranges from 90-120 kg/ha with mean value of 105. The soil phosphorus content ranges from 18-29 kg/ha with mean value of 23.5. The soil potassium content ranges from 142-266 g/kg with mean value of 204. The soil pH content ranges from 5.5-7.2 with mean value of 6.35. While the organic matter content is 3.6%. The study revealed that the highest (204.0) mean value was recorded in potassium content at Site B, while the soil organic matter recorded the least (3.6) mean value at Site B. The lower end of the range (90 kg/ha) can restrict the productivity of crops that require nitrogen, but the mean nitrogen level found is relatively adequate for crop development (Lal, 2020 and Areo, 2023). Practices like green manuring, legume cropping, or the regulated use of nitrogen-based fertilizers are advised in order to maintain soil nitrogen levels. Seed production, energy transmission, and root growth all depend on phosphorus (Marschner, 2012). According to McDowell and Condron (2020), the lower end of the range (18 kg/ha) may limit crop development in phosphorus-deficient soils, even if the mean value is in line with the crucial threshold for the majority of tropical crops. The optimal soil potassium levels for crop productivity are shown by the greatest mean potassium value (204 g/kg) found at Site B. Accordingly, Site B may gain from the use of fertilizers containing potassium or from having adequate natural potassium supplies. With a mean of 6.35 and a range of 5.5 to 7.2, the pH readings showed that the soil was neutral to slightly acidic. Most crops have optimal nutrient availability within this pH range (Havlin *et al.,* 2014). Within the required range of 3–5% for preserving soil health, the organic matter level was 3.6% (FAO, 2017). For long-term crop productivity, organic matter improves soil structure, water retention, and microbial activity (Stockmann, *et. al.,* 2013). This value is sufficient to preserve soil fertility, especially at Site B, despite being the lowest of the values measured. Compost and crop wastes are examples of organic amendments that may be used to improve the soil's long-term quality and organic matter content. The greatest mean potassium concentration (204 g/kg) recorded at Site B implies favourable circumstances for enhancing crop production and resilience. The comparatively lower levels of phosphate and nitrogen, however, suggest that in order to maximize soil fertility, certain nutrient management techniques are required. Although adequate, the amount of organic matter might be increased using sustainable methods to guarantee soil production over the long run.

Table 4: Soil Parameters of Site B in the Study Area

S/N	**Soil parameters**	**Sample B (kg/ha)**	**Mean ± SD**
1	Soil color	Dark gray	-
2	Soil structure	Granular Structure	-
3	Nitrogen	90 – 120	105 ± 8.66
4	Phosphorus	18 – 29	23.5 ± 3.18
5	Potassium	142 – 266	204 ± 35.79
6	pH	5.5 – 7.2	6.35 ± 0.49
7	Organic Matter	3.6	3.6 ± 0

Table 5 shows the results of soil parameters at Site C in the study area. The table shows that the soil colour at Site C is light brown with crumb structure. The soil nitrogen content ranges from 100-134 kg/ha with mean value of 117. The soil phosphorus content ranges from 15-35 kg/ha with mean value of 25. The soil potassium content ranges from 135-239 g/kg with mean value of 187. The soil pH content ranges from 5.6-7.0 with mean value of 6.30. While the organic matter content is 2.5%. The study revealed that the highest (187) mean value was recorded in potassium content at Site C, while the soil organic matter recorded the least (2.5) mean value at Site C. Although crops that require nitrogen, like rice and maize, may not be completely supported by the lower end of the range (100 kg/ha), the observed mean value of nitrogen is sufficient for crop production in tropical soils (Lal, 2020). Utilizing organic fertilizers or leguminous cover crops are examples of integrated nutrient management techniques that are advised to maintain nitrogen levels. For moderate fertility levels, the mean phosphorus value is adequate; but, on phosphorus-deficient soils, the lower range (15 kg/ha) may restrict productivity. By using rock phosphate or phosphorus-enriched organic amendments to increase availability, phosphorus deficits can be controlled (Areo, 2023 and McDowell and Condron, 2020). Enhancing plant water-use efficiency, boosting enzyme activity, and increasing stress tolerance all depend on potassium (Areo, 2022 and Mengel and Kirkby, 2012). The favourable soil conditions for crop growth are shown by the high mean potassium content found at Site C. Such elevated levels might be caused by the use of fertilizers high in potassium or by the natural characteristics of the soil. The soil's pH ranged from 5.6 to 7.0, with a mean of 6.30, indicating neutral to slightly acidic conditions. For the availability of the majority of vital nutrients, this range is ideal (Havlin, 2014). Liming may be necessary for soils with a pH near the lower limit (5.6) in order to improve nitrogen absorption and reduce acidity. In order to maintain optimal soil fertility, the organic matter level should be between 3 and 5%, however it was just 2.5% (FAO, 2017). Water retention, nitrogen cycling, and soil structure are all aided by organic matter (Stockmann, 2013). Given the limited amount of organic matter found at Site C, there may be difficulties maintaining long-term fertility, making the addition of compost, green manure, or organic residues necessary to enhance soil quality. For crops that require potassium, Site C's high potassium level indicates good soil fertility; nevertheless, the low organic matter content raises questions over the soil's long-term health. Although usually beneficial, the moderate amounts of phosphorus and nitrogen may restrict yields for nutrient-intensive crops in the absence of focused management measures.

Table 5: Soil Parameters of Site C in the Study Area

S/N	Soil parameters	Sample C (kg/ha)	Mean ± SD
1	Soil color	Light brown	-
2	Soil structure	Crumb Structure	-
3	Nitrogen	100 – 134	117 ± 9.81
4	Phosphorus	15 – 35	25 ± 5.77
5	Potassium	135 – 239	187 ± 30.01
6	pH	5.6 – 7.0	6.3 ± 0.40
7	Organic Matter	2.5	2.5 ± 0

Table 6 shows the results of soil parameters at Site D in the study area. The table shows that the soil color at Site D is light brown with crumb structure. The soil nitrogen content ranges from 100-150 kg/ha with mean value of 125. The soil phosphorus content ranges from 15-40 kg/ha with mean value of 27.5. The soil potassium content ranges from 150-280 g/kg with mean value of 215. The soil pH content ranges from 5.8-7.1 with mean value of 6.64. While the organic matter content is 1.6%. The study revealed that the highest (215) mean value was recorded in potassium content at Site D, while the soil organic matter recorded the least (1.6) mean value at Site D. Since nitrogen is the building block of proteins, amino acids, and chlorophyll, it is crucial for plant development (Areo, 2023 and Brady and Weil, 2019). The average number shows that the amount of nitrogen in tropical soils is relatively sufficient for crop development. The lower range (100 kg/ha) could, however, restrict yields for crops that require nitrogen, such as wheat and maize. Leaching losses can be decreased and nitrogen levels maintained by including legumes, green manures, and controlled-release nitrogen fertilizers (Lal, 2020). Although the lowest limit of 15 kg/ha may reduce production in phosphorus-deficient areas, the mean phosphorus level is within the ideal range for the majority of crops. Applying phosphate fertilizers, incorporating organic phosphorus sources, or employing microbial in oculants such as arbuscular mycorrhizal fungi can all improve the availability of phosphorus in soils (Areo, 2024 and McDowell and Condron, 2020). Potassium promotes water-use efficiency, controls stomatal activity, and increases stress tolerance (Mengel and Kirkby, 2012). Site D's elevated potassium levels suggest ideal growing conditions for crops that require potassium, such as bananas and potatoes. Mineral weathering or the use of fertilizers high in potassium can cause elevated potassium levels. With a mean pH of 6.64 and a range of 5.8–7.1, the soil conditions were found to be slightly acidic to neutral. According to Havlin (2014), this range is ideal for microbial activity and the availability of vital nutrients. Liming may help decrease acidity in soils with a pH close to the lower limit (5.8), increasing fertilizer availability and absorption efficiency. Out of all the measured metrics, the organic matter content had the lowest recorded value, at 1.6%. Because it improves soil structure, water retention, and nutrient cycling, organic matter is an essential part of soil fertility (FAO, 2017). Concerns regarding soil degradation and long-term productivity are raised by the observed figure, which is below the suggested range of 3–5% (Stockmann, 2013). In order to solve this problem, organic matter should be restored by adding organic amendments like compost, agricultural waste, or animal dung. The greatest mean potassium concentration (215 g/kg) implies that the soil is suitable for crops that need high potassium levels. Nonetheless, possible threats to soil health and long-term agricultural production are indicated by the low organic matter level (1.6%). Although the moderate quantities of phosphate and nitrogen are usually sufficient, crops that require more nutrients could need additional inputs. Improving the amount of organic matter and ensuring balanced fertilization should be the major goals of site-specific soil management techniques.

Table 6: Soil Parameters of Site D in the Study Area

S/N	Soil parameters	Sample D (kg/ha)	Mean ± SD
1	Soil colour	Dark gray	-
2	Soil structure	Granular Structure	-
3	Nitrogen	100 – 150	125 ± 14.43
4	Phosphorus	15 – 40	27.5 ± 7.22
5	Potassium	150 – 280	215 ± 37.5
6	pH	5.8 – 7.1	6.64 ± 0.38
7	Organic Matter	1.6	1.6 ± 0

Table 7 compares the results of soil parameters across the four sites (A, B, C and D) in the study area. The table shows that from site A to D; the highest (125) nitrogen content was recorded at site D while the least (105) was recorded at site B. The highest (27.5) phosphorus content was recorded at site D while the least (23) was recorded at site A. The highest (215) potassium content was recorded at site D while the least (187) was recorded at site C. The highest (6.64) pH content was recorded at site D while the least (6.25) was recorded at site A. The highest (2.8) organic matter content was recorded at site C while the least (1.5) was recorded at site D. In contrast to Site B, where nitrogen levels were lowest, Site D's greatest nitrogen concentration indicates superior soil fertility. Variations in the amount of organic matter or nitrogen management techniques like crop rotation or fertilizer application might be the cause of this fluctuation. For nitrogen-intensive crops like rice or maize, yields may be limited if nitrogen levels fall below 120 kg/ha, as shown at Site B (Lal, 2020). Site D's greatest phosphorus level suggests ideal circumstances for phosphorus absorption, most likely as a result of improved phosphorus management or natural soil characteristics. On the other hand, Site A's reduced phosphorus level can lead to less-than-ideal crop development. Phosphorus availability can be increased, especially in Site A, by using rock phosphate or microbial inoculants such as arbuscular mycorrhizal fungi (Areo, 2024; McDowell and Condron, 2020). At Site C, the potassium concentration was 187 g/kg, whereas at Site D, it was 215 g/kg. According to Mengel and Kirkby (2012), potassium is essential for plant stress tolerance, water-use efficiency, and enzyme activation. While the lower potassium levels at Site C could restrict yield, the greatest values at Site D indicate ideal circumstances for crops that require potassium. Different fertilizer applications or variations in soil mineralogy may be the cause of variations in potassium concentration. The pH of the soil varied from 6.25 at Site A to 6.64 at Site D, suggesting that the conditions were neutral to slightly acidic. Most important nutrients are most available in a pH range of 6.0 to 7.0 (Havlin, 2014). While the slightly lower pH at Site A could necessitate liming to improve nutrient accessibility, the higher pH at Site D probably promotes improved microbial activity and nutrient availability. At Site D, the organic matter concentration was 1.5%, while at Site C, it was 2.8%. Because it affects soil structure, water retention, and nutrient cycling, organic matter is a crucial indication of soil health (FAO, 2017). Concerns regarding soil fertility and long-term production are raised by Site D's low organic matter level. On the other hand, Site C's increased organic matter indicates superior soil quality, most likely as a result of less degradation or the buildup of organic residue. It is advised to use techniques like adding compost, green manure, or agricultural residues to increase the amount of organic matter, especially at Site D (Stockmann, 2013). The greatest amounts of nitrogen, phosphate, potassium, and pH were continuously found at Site D, suggesting comparatively improved soil fertility conditions. Its 1.5% organic matter concentration, however, could present long-term problems for soil production. The necessity of balanced nutrient management was highlighted by Site C, which had the highest organic matter concentration (2.8%) but the lowest potassium amount. Improving soil fertility at each location requires site-specific measures including increasing organic matter and optimizing fertilizer.

Table 7: Comparison of Soil Properties across the Sites in the Study Area

S/N	Soil parameters	Sample A (kg/ha)	Sample B (kg/ha)	Sample C (kg/ha)	Sample D (kg/ha)
1	Nitrogen	121.5	105	117	125
2	Phosphorus	23	23.5	25	27.5
3	Potassium	210.5	204	187	215
4	pH	6.25	6.35	6.30	6.64
5	Organic Matter	2.8	3.6	2.5	1.6

Table 8 shows the comparison of the soil parameters obtained at sites A, B, C and D, and the FAO standard values for rice farming in 2023. The table shows that soil nitrogen, phosphorus and organic matter contents at sites A to D were within the ranges of the FAO standard values for rice farming of 2023. The soil potassium contents at sites A to D are higher above range of the FAO standard values for rice farming of 2023. The soil pH at sites A to C are within the range of the FAO standard values for rice farming of 2023 except that of site D with a difference of 0.14. This study compared the FAO standard values for rice growing in 2023 with the soil parameters at four distinct sites (A to D). Nitrogen, phosphorus, potassium, pH, and organic matter concentrations are among the soil factors taken into account. The FAO guidelines for the best rice growing practices and contemporary academic research are cited in the discussion of the findings that follows. The FAO standard values for rice farming (2023) are met by the soil nitrogen levels at Sites A through

D, suggesting that there is sufficient nitrogen available for rice production at these locations. For rice plants, nitrogen is a crucial macronutrient that supports the synthesis of proteins, chlorophyll, and general plant development (Brady and Weil, 2019). For rice production, the FAO advises keeping nitrogen levels between 100 and 120 kg/ha to provide the best possible plant development and output (FAO, 2023). According to the study's findings, these locations appear to satisfy rice's nitrogen needs, which are essential for producing yields that are sufficient. In a similar vein, the FAO standard range for rice cultivation is met by the soil phosphorus concentrations at Sites A through D (2023). In rice plants, phosphorus is essential for seed production, energy transmission, and root growth (Marschner, 2012). In order to provide sufficient nutrient availability for good growth, the FAO advises rice farmers to use phosphorus levels of about 20 to 30 kg/ha. According to the study's findings, the phosphorus levels are ideal for sustaining strong root systems and boosting the general growth of rice crops in all locations. Additionally, the organic matter level at Sites A through D is within the FAO's recommended limit for rice cultivation (2023). According to the FAO (2017), organic matter is essential for preserving soil structure, boosting microbial activity, and promoting nutrient and water retention. According to this study, sufficient organic matter enhances soil fertility and sustainability in rice cultivation. According to the findings, there is enough organic matter present at these locations to maintain ecologically friendly and fruitful rice cultivation methods. The soil potassium level at Sites A through D is higher than the FAO standard standards for rice growing (2023), in contrast to nitrogen, phosphorus, and organic matter. In rice plants, potassium is essential for stress tolerance, water control, and enzyme activation (Mengel and Kirkby, 2012). According to FAO criteria, for the best rice production, the potassium level should be between 150 and 250 g/kg. The advantageous mineral makeup of the soils or the use of fertilizers high in potassium may be the cause of the greater potassium concentration at these locations. While certain situations may benefit from having too much potassium, it's crucial to keep an eye on and control potassium levels since imbalances can harm plant development and nutrient absorption (Abdullahi, 2024; Havlin, 2014). The pH of the soil at Sites A through C is between 5.5 and 7.0, which is the range that the FAO recommends for rice cultivation (FAO, 2023). Microbial activity, nutrient availability, and general soil health are all impacted by soil pH. For rice production, a pH range of 5.5 to 6.5 is optimal because it guarantees optimal nutrient availability (Havlin, 2014). With a pH difference of 0.14 from the FAO norm, Site D's slightly higher pH may somewhat restrict nutritional availability, especially for micronutrients. If this pH fluctuation persists, it could be necessary to make minor changes, such adding soil amendments, to bring the pH down to the ideal range for rice cultivation. A suitable environment for rice production is shown by the results, which indicate that the nitrogen, phosphorus, and organic matter concentrations at Sites A through D meet or coincide with the FAO standard values for rice farming (2023). High potassium levels, however, may cause nutrient absorption imbalances, particularly if potassium availability becomes unmanageable, which may impair the effectiveness of other nutrients (Areo, 2024; Mengel and Kirkby, 2012). Furthermore, the little pH variation at Site D emphasizes the necessity of close observation and potential modification to maximize microbial activity and nutrient availability for rice crops.

Table 8: Comparison of Soil Properties with FAO Standard

Soil parameters	**Sample A (kg/ha)**	**Sample B (kg/ha)**	**Sample C (kg/ha)**	**Sample D (kg/ha)**	**FAO Standard for Rice Farming 2023**
Nitrogen	121.5	105	117	125	50–150
Phosphorus	23	23.5	25	27.5	20–40
Potassium	210.5	204	187	215	80–120
pH	6.25	6.35	6.30	6.64	5.5–6.5
Organic Matter	2.8	3.6	2.5	1.6	2–4

Table 9 shows the SPSS results of the Analysis of Variance (ANOVA) for soil parameters for sites A, B, C and D. From the table, the F ratio value is 0.335. Within samples and between samples with 55 and 37 degrees of freedom have critical F values of 244.60 and 218.21, respectively, at a confidence level of 0.005. These numbers exceeded the F value of 0.335. This implies that there are variations in the soil parameters in the study area, and those variations are substantial. Therefore, the Null Hypothesis (Ho) which states that there is no significant variation in the nitrogen, phosphorus, potassium, pH and organic matter contents of rice farm in the study area is thereby rejected. And that there is a significant variation in the soil parameters across the four sites (A to D) in the study area. For rice production, the differences in soil properties across the four locations (A to D) are very significant. These factors—which include the levels of nitrogen, phosphorus, potassium, pH, and organic matter—are crucial in influencing the fertility of the soil and, in turn, the yield of rice fields. Numerous factors, such as soil type, climate, land management techniques, and fertilization history, can affect these components' variability (Brady and Weil, 2019). To maximize rice production in the research region, site-specific soil management techniques are required, as indicated by the notable variations between the sites. The necessity of site-specific soil management is shown by the null hypothesis' rejection. Key soil factors vary throughout the research region, indicating that a one-size-fits-all method of growing rice would not work. Rather, producers should think about things like site-specific pH changes, fertilizer management, and soil fertility levels.

Table 9: Mean Variation of Soil Parameters at Sites A, B, C and D

Model		**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
1	(Constant)	244.60	55	25.320	.335	.005[b]
	Soils	218.21	37	18.133		
	Total	**462.81**	**92**	**43.453**		

[a]Dependent variables: Soil properties

[b]Constant variables: Soils

Table 10 shows the SPSS results of the Analysis of Variance (ANOVA) for soil parameters and FAO standard. From the table, the F ratio value is 0.323. Within samples and between samples with 43 and 28 degrees of freedom have critical F values of 201.41 and 199.22, respectively, at a confidence level of 0.005. These values are greater than the F value of 0.335. This indicates that there are variations in the soil parameters and FAO standard in the study area, and those variations are not too prominent. Therefore, the Null Hypothesis (Ho) which states that there is no significant variations in nitrogen, phosphorus, potassium, pH and organic matter contents of rice farm and the FAO Standard is thereby rejected. It is crucial to recognize that minor discrepancies still exist even if the data show that the disparities between soil characteristics and the FAO requirements are not very substantial. These little differences may have real-world effects on crop management techniques in the research region. For example, the growth, nutrient absorption, and total yield of rice plants can be impacted by soil characteristics including pH, phosphate, potassium, and nitrogen. For the best rice production, even minor deviations from the FAO guidelines may have an impact on irrigation techniques, soil amendment plans, and fertilizer management (FAO, 2023). The null hypothesis' rejection suggests that there are, in fact, some, however little, discrepancies between the measured soil parameters and the FAO standard values. Despite not being statistically significant at the 0.005 confidence level, these variations are nonetheless crucial for comprehending soil health and might point to regions where soil management techniques need to be improved. For example, little variations in the amount of organic matter (e.g., mild variations in pH or nitrogen levels) may affect the structure and nutrient cycling of the soil, which may affect the quality and production of rice (Abdullahi, 2024; Marschner, 2012).

Table 10: Variation of Soil Parameters for A, B, C and D Sites, and FAO Standard 2023 for Rice Farming

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	(Constant)	201.41	43	23.112	.323	.005[b]
	Soils	199.22	28	14.130		
	Total	**400.63**	**71**	**37.242**		

[a]Dependent Variables: Soil properties
[b]Constant Variables: FAO standard.

Conclusion

The study concludes that the soil colour and structure varied from site to site, affecting soil properties, and potassium maintained the highest mean values across all sites, while organic matter had the lowest. The limited amount of organic matter suggests low levels of soil organic carbon, which might restrict long-term soil sustainability and productivity by influencing microbial activity, water retention, and soil structure. These results emphasize the necessity of site-specific soil management techniques, such enriching soil with organic matter, to improve soil health and agricultural productivity.

Recommendations

The study recommended that:

i. Farmers in Gwagwalada should be encouraged to adopt soil conservation techniques such as terracing, and mulching. These practices help maintain soil structure, and enhance water retention, which are critical for sustainable rice production.
ii. The application of organic materials like compost and farmyard manure, alongside judicious use of inorganic fertilizers, should be promoted. This approach enhances soil fertility by replenishing nitrogen, phosphorus, and potassium levels, as well as increasing organic matter content, thereby improving rice yields.
iii. Regular soil testing should be conducted to monitor and manage soil pH levels. Where deviations occur, lime or sulfur applications should be used to correct pH imbalances. This will ensure optimal nutrient availability and uptake for rice plants.
iv. Agricultural extension services should be strengthened to provide training for farmers on soil conservation and sustainable agricultural practices.

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