

SOIL FERTILITY INDICES OF SMALLHOLDER FARMS IN DABERAM IRRIGATION SCHEME, KATSINA STATE, NIGERIA

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Abstract

This study investigated the physical and chemical properties of soils on smallholder farms at the Daberam Irrigation Scheme in Katsina State, Nigeria. The objectives were to examine crops and cropping systems in practice, determine soil physical and chemical properties, and assess the soil fertility status and its impacts on crop yields. A descriptive research design was adopted, combining laboratory soil analyses with structured questionnaire surveys administered to 120 randomly selected farmers using stratified random sampling. twelve composite soil samples were collected using stratified sampling from four farm plots at a depth of 0–15 cm and analyzed for Soil pH, Organic Carbon (OC), Total Nitrogen (TN), Available Phosphorus (P), Cation Exchange Capacity (CEC), Water Holding Capacity (WHC), and Particle Size Distribution (PSD). Results indicated moderately acidic to near-neutral soils (pH 5.7–6.9), with moderate organic matter (mean 2.35%), medium total nitrogen (mean 0.34%), medium phosphorus availability (2.97g/kg, and low CEC (mean 9.51 cmol/kg) and correlation analysis showed pH and Nitrogen to be more relevant soil properties. Soil texture was predominantly loamy sand and sandy loam (mean sand 81.61%), indicating moderate soil fertility. Farmers cultivate onions, vegetables, and tomatoes under surface irrigation, with widespread use of combined organic and inorganic fertilizers. Conservation tillage, crop rotation, and cover cropping are commonly practiced. Key challenges include high input costs, soil nutrient depletion, limited soil testing, and low innovation adoption. The study recommends integrated soil fertility management, government input subsidies, expanded extension training, and promotion of soil testing to sustain agricultural productivity at the scheme.

Keywords: Soil Fertility; Physicochemical Properties; Irrigation Farming; Smallholder Agriculture; Katsina State; Integrated Soil Fertility Management

Introduction

Soil fertility is fundamental to agricultural productivity, particularly in irrigation schemes across semi-arid regions where sustainable farming depends on the health of the soil resource (Sanchez, 2002; Vanlauwe *et al.*, 2010). In sub-Saharan Africa, declining soil fertility has been identified as one of the most critical constraints to food security, with smallholder farmers in semi-arid Nigeria disproportionately affected by nutrient depletion, inadequate input access, and limited technical support (Brady and Weil, 2017; Bationo *et al.*, 2012). Understanding the physical and chemical properties of irrigated soils is therefore essential for designing management strategies that maintain or restore productivity.

The Daberam Irrigation Scheme in Daura Local Government Area, Katsina State, Nigeria, provides a critical context for this inquiry. Prior research at the scheme has focused primarily on water availability constraints and general soil management practices across northern Katsina (El-Ladan and Rumah, 2015; El-Ladan and Maiwada, 2014). However, a targeted analysis of the soil's physical and chemical properties under irrigation, and their interplay with farmer management practices and crop productivity, has not been previously undertaken.

This study addresses this research gap by investigating the physico-chemical properties of soils on smallholder farms at the Daberam Irrigation Scheme. The specific objectives were to: (i) examine the types of crops and cropping systems practiced; (ii) determine the soil physical and chemical properties under irrigation; and (iii) assess the soil fertility status and its impact on crop yields. The findings are intended to inform targeted interventions for soil fertility management, extension services, and agricultural policy in northern Nigeria.

Literature Review

Soil Fertility in Smallholder Irrigation Systems

Soil fertility, broadly defined as the ability of soil to supply the nutrients required for plant growth, represents an ecosystem concept integrating diverse soil functions including nutrient supply, organic matter cycling, and biological activity (Swift and Palm, 2000; Singh *et al.*, 2013). In tropical smallholder systems, soil fertility decline is driven by continuous cropping, insufficient nutrient replenishment, erosion, and leaching losses, particularly in coarse-textured soils common in semi-arid Nigeria (Sanchez, 2002; Brady and Weil, 2017).

Laboratory-measured physicochemical parameters including soil pH, organic carbon (OC), total nitrogen (TN), available phosphorus (P), cation exchange capacity (CEC), and water holding capacity (WHC) provide critical indicators of soil health and crop production potential. Brady and Weil (2017) emphasize that nutrient availability, microbial activity, and root function are all sensitive to these parameters and that their management is central to sustainable agricultural intensification.

Soil Fertility Research in Northern Nigeria and Related Contexts

El-Ladan and Maiwada (2014) reported very low fertility indices in cultivated smallholder lands in Jibia Local Government Area, Katsina State, noting higher sand percentages in cultivated lands compared to uncultivated lands. El Ladan and Rumah (2015) similarly found low nutrient content in soils of northern Katsina while emphasizing the need for careful management to prevent erosion and yield decline. More recently, Yakubu and Mallo (2019) assessed soil fertility under continuous irrigation farming in the Nigerian Savanna, reporting loamy textures and recommending regular soil testing.

Comparable findings have been reported from other smallholder irrigation contexts across Africa. Wawire *et al.* (2021) in Kenya found that socio-economic and institutional factors critically influence adoption of Integrated Soil Fertility Management (ISFM) practices. Turamyenyirijuru *et al.* (2024) documented slightly to moderately acidic soils in Rwandan smallholder farms, with significant within-site variability in key fertility parameters. Njoloma *et al.* (2016) found low organic matter and nitrogen in Malawian smallholder soils, stressing the need for sustainable soil management practices.

Theoretical Framework: Integrated Soil Fertility Management (ISFM)

This study is framed within the theory of Integrated Soil Fertility Management (ISFM), which combines the use of mineral fertilizers, organic resources, improved seed varieties, and agronomic best practices to maximize nutrient efficiency and maintain soil health (Vanlauwe *et*

al., 2010; Bationo *et al.*, 2012). ISFM principles recognize that neither mineral fertilizers alone nor organic inputs alone are sufficient to restore and sustain soil fertility in degraded smallholder systems, but that their strategic combination can achieve synergistic benefits for soil structure, nutrient cycling, and crop productivity (Vanlauwe *et al.*, 2010). This framework directly informs the study's assessment of soil parameters and farmer practices at Daberam.

Materials and Methods

Study Area

The Daberam Irrigation Scheme is located in Daura Local Government Area, Katsina State, Nigeria, between latitudes 12°50.04'N to 13°52.02'N and longitudes 8°04.30'E to 8°24.00'E. The study area falls within the semi-arid zone, characterized by annual rainfall of 400–600 mm, a mean annual temperature of approximately 28°C, and a growing season spanning June to September (Nigerian Meteorological Agency, 2016). Soils in the area are derived from sedimentary formations and are characterized as coarse-textured, low-to-medium fertility, and well-drained, primarily suited to millet, groundnut, sorghum, and cowpea (KTARDA, 2009). The irrigation scheme relies on Daberam Dam as its principal water source, supporting dry-season cultivation of high-value vegetables, onions, and tomatoes.

Research Design

A descriptive research design was employed, integrating laboratory soil analyses with structured farmer surveys to characterize soil fertility status and examine farming system dynamics.

Sampling Techniques and Sample Size

Using Yamane's (1967) formula ($n = N / [1 + Ne^2]$) at a 95% confidence level and 5% margin of error, a sample size of 120 farmers was derived from an estimated population of 170 farmers in the scheme. Stratified random sampling was applied, proportionally allocating 85 respondents to irrigated farmers and 35 to non-irrigated farmers, ensuring representation of different soil management systems.

For soil sampling, twelve composite soil samples were collected from four farm plots stratified by management practice (1, monocropping, 2, mixed cropping, and 3, non-irrigated land, 4 ?). Five sub-samples were collected per plot at 0–15 cm depth using soil auger, bulked, and approximately 0.5 kg was bagged using quatering method and labelled A1, A2, A3, B1, B2, B3, C1, C2, C3, D1, D2, D3 for laboratory analysis.

Laboratory Analyses

Soil samples were air dried and analyzed at the Soil Laboratory, Umaru Musa Yar'adua University, Katsina using standard methods: soil pH was measured using pH meter (1:2.5 soil-water ratio); Organic Carbon (OC) was determined by the Walkley-Black method; Total Nitrogen (TN) by the Micro-Kjeldahl method; Available Phosphorus using Bray-1 method; ; Cation Exchange Capacity (CEC) by the; Available Water Holding Capacity (WHC) using Automatic Hydrometer; and Particle Size Distribution (PSD) by Hydrometer method.

Data Collection and Analyses

Primary data from farmer surveys covered cropping systems, tillage practices, fertilizer use, yield trends, soil problems, and access to extension services. Data were analyzed using descriptive statistics (frequencies and percentages).. Correlation analysis and regression models were applied to examine the relationship between soil fertility parameters and reported crop yield outcomes. All analyses were conducted using standard statistical procedures.

Results and Discussions

Soil Physicochemical Properties

Laboratory analyses result of the soil samples revealed moderately acidic to near-neutral pH values (5.7–6.9, mean 6.48), indicating generally favourable conditions for nutrient availability. Organic Carbon ranged from 1.02% to 1.82% (mean 1.36%), corresponding to Organic Matter values of 1.76–3.14% (mean 2.35%), suggesting moderate fertility buffering. Total Nitrogen averaged 0.34%, indicating low nitrogen reserves requiring supplementation. Available Phosphorus averaged 2.97 g/Kg (medium level), and CEC ranged from 8.90 to 10.32 cmol/kg (mean 9.51 cmol/kg), reflecting low nutrient retention. Water Holding Capacity showed notable spatial variability (7.66–18.02 Mg/l, mean 12.05 Mg/l) which is very low.

Table 1: Soil Physicochemical Properties of Selected Farm Plots

Sample	pH	OC (%)	OM (%)	TN (%)	AV.P (g/kg)	CEC (cmol/kg)	WHC (Mg/l)
A1	6.4	1.412	2.434	0.521	3.46	9.31	09.05
A2	6.6	1.322	2.279	0.236	2.62	9.62	11.71
A3	6.3	1.021	1.760	0.162	2.11	8.90	07.66
B1	6.8	1.631	2.811	0.342	2.20	9.11	12.23
B2	6.5	1.522	2.623	0.416	2.96	9.17	08.03
B3	5.7	1.211	2.087	0.293	3.38	10.11	16.37
C1	6.8	1.062	1.830	0.161	3.86	10.21	18.02
C2	6.2	1.312	2.261	0.460	3.10	10.32	16.42
C3	6.4	1.126	1.941	0.212	3.42	9.63	15.24
D1	6.9	1.823	3.142	0.696	2.16	9.44	09.40
D2	6.7	1.532	2.641	0.234	2.66	9.21	10.62
D3	6.4	1.396	2.406	0.332	3.76	9.14	09.79
Mean	6.5	1.36	2.35	0.34	2.97	9.51	12.05

Note: OC = Organic Carbon; OM = Organic Matter; TN = Total Nitrogen; AV.P = Available Phosphorus; CEC = Cation Exchange Capacity; WHC = Water Holding Capacity. Source: Laboratory Analysis, 2025.

The moderately acidic to near-neutral pH values recorded fall within the range considered optimal for nutrient availability in tropical agricultural soils (Brady and Weil, 2017; FAO, 2006). This pH range supports Phosphorus availability, Nitrogen transformation, and Microbial activity, all of which are critical for crop productivity (Havlin *et al.*, 2014). The moderate Organic Matter values (mean 2.35%) suggest some fertility buffering capacity, though Vanlauwe *et al.*, (2010) and Sanchez (2002) caution that declining Organic Matter remains one of the most critical drivers of soil fertility loss in smallholder systems across sub-Saharan Africa.

Low total nitrogen (mean 0.34%) is consistent with findings from comparable irrigation contexts in northern Nigeria (Yakubu and Mallo, 2019) and across Africa (Bationo *et al.*, 2012). Nitrogen depletion in sandy irrigated soils is accelerated by leaching, volatilization, and continuous crop removal. The low CEC (mean 9.51 cmol/kg) indicates limited buffering of nutrient losses, emphasizing the need for split fertilizer applications and organic matter additions to sustain productivity (Brady and Weil, 2017; Landon, 1991). The results are summarized in Table 1.

Correlation Analysis

Correlation analysis was carried out to assess the relationships between yield as the dependent variable and selected soil properties as independent variables, using a sample size of N=12. The results showed that yield had a moderate positive correlation with total nitrogen ($r = 0.441$, $p = 0.151$), suggesting that higher nitrogen content was associated with increased yield, though the relationship was not statistically significant at $p < 0.05$. Yield also exhibited a moderate negative correlation with soil pH ($r = -0.392$, $p = 0.208$), indicating that more acidic or alkaline conditions tended to reduce yield. Available phosphorus showed a weak positive correlation with yield ($r = 0.262$, $p = 0.410$), while cation exchange capacity ($r = -0.110$, $p = 0.734$), organic carbon ($r = 0.033$, $p = 0.920$), organic matter ($r = 0.034$, $p = 0.917$), and water holding capacity ($r = -0.228$, $p = 0.475$) all had very weak or negligible correlations with yield. None of the correlations with yield were statistically significant, likely due to the small sample size. Among the soil properties, total nitrogen and pH demonstrated the strongest associations with yield and appear to be the most influential factors affecting yield variability in this study, while other variables showed minimal direct linear relationships.

Table 2: Correlation Analysis of Farm Yields and Soil Properties

		pH	OC	OM	TN	AV.P	CEC
pH	Pearson Correlation	1	.492	.492	.155	-.335	-.318
	Sig. (2-tailed)		.104	.104	.630	.287	.314
	N	12	12	12	12	12	12
OC	Pearson Correlation	.492	1	1.000**	.749**	-.439	-.348
	Sig. (2-tailed)	.104		.000	.005	.154	.267
	N	12	12	12	12	12	12
OM	Pearson Correlation	.492	1.000**	1	.749**	-.438	-.349
	Sig. (2-tailed)	.104	.000		.005	.154	.266
	N	12	12	12	12	12	12
TN	Pearson Correlation	.155	.749**	.749**	1	-.188	-.033
	Sig. (2-tailed)	.630	.005	.005		.559	.919
	N	12	12	12	12	12	12
AV.P	Pearson Correlation	-.335	-.439	-.438	-.188	1	.491
	Sig. (2-tailed)	.287	.154	.154	.559		.105
	N	12	12	12	12	12	12
CEC	Pearson Correlation	-.318	-.348	-.349	-.033	.491	1
	Sig. (2-tailed)	.314	.267	.266	.919	.105	
	N	12	12	12	12	12	12
WHC	Pearson Correlation	-.248	-.441	-.442	-.308	.497	.893**
	Sig. (2-tailed)	.437	.151	.150	.329	.100	.000
	N	12	12	12	12	12	12
Yield	Pearson Correlation	-.392	.033	.034	.441	.262	-.110
	Sig. (2-tailed)	.208	.920	.917	.151	.410	.734
	N	12	12	12	12	12	12

Soil Textural Classification

Soil texture analysis demonstrated a dominant sandy character across all sampling points. Mean particle size fractions were 81.61% sand, 14.44% clay, and 3.96% silt. Textural classes were predominantly loamy sand and sandy loam, with no fine-textured soils recorded (Table 2). The high sand content implies good drainage and tillage ease, but limited water and nutrient retention capacity.

Table 2: Soil Textural Classification of Selected Farm Plots

Sample	Sand (%)	Clay (%)	Silt (%)	Textural Class
A1	77.52	17.18	5.48	Sandy Loam
A2	71.52	23.20	5.28	Sandy Loam
A3	84.80	11.92	3.28	Loamy Sand
B1	86.80	11.92	1.28	Loamy Sand
B2	80.80	15.92	3.28	Loamy Sand
B3	79.52	13.20	7.28	Loamy Sand
C1	87.52	11.20	1.28	Sandy Loam
C2	89.52	9.20	1.28	Sandy Loam
C3	75.52	17.20	7.28	Loamy Sand
D1	79.52	15.20	5.28	Loamy Sand
D2	83.52	13.20	3.28	Sandy Loam
D3	82.80	13.92	3.28	Sandy Loam
Mean	81.61	14.44	3.96	—

Source: Laboratory Analysis, 2025.

Farming Practices

Socioeconomic profiling revealed a 100% male farming population, predominantly in the 46–55-year age bracket (24%), with low formal education (43% non-formal, 41% primary). Farm sizes were mostly 1–2 hectares (54%), confirming the smallholder nature of the scheme. Farming experience was generally high, with 32% of respondents having over 20 years of experience.

The main crops grown were onions (49%), leafy vegetables (46%), tomatoes (43%), rice, and maize (38% each). Surface irrigation was dominant (70%), with drip (8%) and sprinkler (22%) systems less common. A summary of key farming practice variables is presented in Table 3.

Farming Challenges

The major challenges reported by respondents are summarized in Table 4. High input costs (46%), limited access to fertilizers and pesticides (43%), and market access issues (41%) were the dominant constraints. Pest and disease outbreaks affected 32% of respondents, while only 27% had ever conducted a soil test, and only 19% had received formal training on sustainable farming practices.

Table 3: Summary of Key Farming Practices Among Respondents (n = 120)

Farming Practice/Variable	Frequency	Percentage (%)
Surface irrigation	84	70
Drip irrigation	10	8
Sprinkler irrigation	26	22
Fertilizer use (Yes)	104	86
Both organic & inorganic fertilizer	97	81
Minimum tillage	82	68
No-tillage	26	22
Crop rotation (Yes)	94	78
Cover cropping (Yes)	120	100
Extension support received (Yes)	91	76
Training on sustainable practices (Yes)	23	19

Source: Field Survey, 2025. Note: Percentages for multi-response items exceed 100%.

Farming Challenges

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Table 4: Major Challenges (n = 120)

Challenge	Frequency	Percentage (%)
High cost of inputs	55	46
Lack of fertilizers/pesticides	52	43
Market access issues	49	41
Pest and disease outbreaks	38	32
Inadequate water supply	24	20
Lack of quality seeds	19	16
Poor infrastructure	18	15
Lack of labour	10	8

Source: Field Survey, 2025.

The predominance of loamy sand and sandy loam soils (mean sand 81.61%) is consistent with the sedimentary geology of northern Katsina (El-Ladan and Maiwada, 2014) and is characteristic of many semi-arid irrigation landscapes in Nigeria (Musa *et al.*, 2013). While these soils facilitate tillage and reduce waterlogging risk, their low clay and silt content limits nutrient and water

retention, increasing vulnerability to leaching under irrigation (Havlin *et al.*, 2014; Sanchez, 2002). Organic matter incorporation and conservation tillage are particularly important management responses in these coarse-textured soils (Lal, 2004; Vanlauwe *et al.*, 2010).

The widespread adoption of combined organic and inorganic fertilizers (81%) among Daberam farmers reflects an emerging alignment with Integrated Soil Fertility Management principles. As Vanlauwe *et al.*, (2010) demonstrate, integrating mineral fertilizers with organic inputs improves nutrient use efficiency and supports soil structure in sandy soils. The predominance of minimum tillage (68%) and universal coverage of crop cover cropping (100%) further supports soil structural integrity and organic matter inputs.

However, near-exclusive dependence on markets for fertilizer input (89%) creates vulnerability to supply shocks and price volatility, while only 27% of farmers have ever conducted soil testing. These patterns mirror findings by Akinbode *et al.*, (2024) in southwest Nigeria, who found that most farmers relied on non-scientific indicators of soil fertility, limiting the precision of their management decisions.

Yield Trends, Innovation Adoption and Support Gaps

The majority of respondents (78%) reported yield increases over the past five years, consistent with improved fertilizer use, reliable irrigation water, and growing experience. Nevertheless, only 11% had adopted new farming technologies, reflecting barriers including high costs, risk aversion, and limited training documented in adoption literature (Feder *et al.*, 1985; Rogers, 2003). That 96% of trained farmers consistently applied sustainable techniques underscores the transformative potential of targeted extension, if systematically scaled (FAO, 2010).

Conclusion and Recommendations

This study provides the first targeted assessment of soil physico-chemical properties under irrigation at the Daberam Irrigation Scheme, Katsina State, Nigeria. The soils are characterized by moderate fertility (moderate OC, OM, and CEC; low TN), a predominantly sandy texture with limited water and nutrient retention, and near-neutral pH values broadly suitable for crop production although pH and Nitrogen were the strongest factors. While farmers demonstrate emerging alignment with Integrated Soil Fertility Management (ISFM) principles through combined fertilizer use, conservation tillage, and crop rotation, critical gaps persist in soil testing uptake, innovation adoption, training coverage, and institutional input support.

Based on these findings, the study makes the following recommendations:

- i. Government agencies should subsidize and ensure timely delivery of quality fertilizers and other soil inputs to reduce the financial burden on smallholder farmers and improve productivity.
- ii. Extension services and research institutions should scale up training on the importance and methods of regular soil testing, enabling evidence-based fertility management at plot level.
- iii. Agricultural development projects should establish community-based demonstration farms and farmer field schools to promote adoption of climate-smart and ISFM-aligned practices.
- iv. NGOs and development partners should invest in capacity-building programs targeting older and less formally educated farmers, who constitute the majority of the farming population at the scheme.

- v. Farmer cooperatives should strengthen collective input sourcing and peer learning mechanisms to improve affordable access to soil management services and knowledge exchange.

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