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Research Article

Assessment of Soil Health Status and Exploring the Potential of Its Improvement Using Cover Crops in Dutsin-Ma, Katsina State

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ABSTRACT
This study assessed the soil health status of Dutsin-Ma by evaluating key physical, chemical, and biological properties. Soil samples were collected using a grid pattern, air-dried, and analyzed for various parameters, including soil texture, pH, organic carbon, total nitrogen, available phosphorus, exchangeable bases, and micronutrient concentrations. The results indicate that the soil in Dutsin-Ma is predominantly sandy loam, with a slightly acidic pH (mean = 5.77) and moderate levels of available phosphorus (mean = 3.2 mg/kg). However, organic carbon (mean = 0.57%) and total nitrogen (mean = 0.05%) were found to be low, which may limit microbial activity and crop productivity. The cation exchange capacity (CEC) was moderate (mean = 3.24 cmol(+)/kg), indicating a fair ability to retain essential nutrients. Micronutrient analysis revealed that zinc (mean = 4.75 mg/kg), copper (mean = 2.70 mg/kg), manganese (mean = 25.50 mg/kg), and iron (mean = 116.83 mg/kg) were within acceptable ranges for crop growth, though iron variability suggests possible uptake challenges. Salinity parameters showed a high base saturation percentage (mean = 99.21%), low sodium adsorption ratio (mean = 0.08), and moderate magnesium hazard (mean = 25.00), indicating potential risks of soil structure deterioration over time. The study highlights the need for soil management practices such as organic amendments, cover cropping, and balanced fertilization to improve soil fertility and nutrient availability. Therefore, the outcomes of this research is recommended to be utilized by policymakers, researchers, and farmers in making informed decisions to enhance soil quality and long-term productivity in the region.

Keywords: Cover crops; Nutrients; Salinity; Soil health; Soil Fertility

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INTRODUCTION

Soil health is a critical determinant of agricultural productivity and environmental sustainability (Li *et al.;* 2025). It encompasses the physical, chemical, and biological properties of soil that support plant growth, maintain ecosystem balance, and resist degradation (Doran & Zeiss, 2000). Soil health is dynamic and influenced by natural processes and human activities such as deforestation, overgrazing, and intensive farming (Shukhla 2022). In semi-arid regions like Katsina State, the challenge lies in balancing agricultural intensification with soil conservation. The assessment of soil health is essential for optimizing land use, improving crop yield, and mitigating environmental risks, particularly in semi-arid regions such as Dutsin-Ma, Katsina State (Ruma, 2011; Acosta-Martinez *et al.;* 2023).

Dutsin-Ma, located in northern Nigeria, experiences a predominantly dry climate with seasonal rainfall variability, which significantly influences soil properties and agricultural potential (Ojanuga, 2006). Over the years, factors such as land-use changes, intensive farming, and fertilizer application have raised concerns about soil degradation in the region (Ruma, 2011). Consequently, assessing the soil health status of

Dutsin-Ma is crucial for sustainable land management, ensuring long-term productivity and environmental conservation.

Soil health indicators include physical attributes such as soil structure, bulk density, and water-holding capacity; chemical properties like pH, organic matter content, and nutrient levels; and biological factors such as microbial diversity and enzyme activity (Bünemann *et al.;* 2018). Evaluating these indicators provides insights into soil fertility, nutrient cycling efficiency, and overall ecosystem functionality (He *et al.;* 2021).

Smallholder farmers primarily rely on traditional methods like crop rotation and manuring to maintain soil fertility, with limited knowledge of scientific approaches (Muhammad & Saba, 2024). Soil quality is affected by both natural and anthropogenic factors, including agricultural practices, deforestation, and erosion (Aliyev, 2018). eavy metal contamination in agricultural soils has been assessed, with most metals found within acceptable limits, though some areas show moderate pollution, particularly with iron (Yaradua *et al.;* 019; Yaradua *et al.;*022). While the overall ecological risk is low, there are concerns about potential health risks, especially for children exposed to lead in certain zones (Yaradua *et al.;* 2022).

This study aims to assess the current soil health status of Dutsin-Ma, Katsina State, by analyzing key soil properties. The findings will contribute to a better understanding of soil conditions in the area, inform soil management practices, and support sustainable agricultural development.

MATERIALS AND METHODS

Experimental Site

The study was conducted in Dutsin-Ma Local Government Area, Katsina State, Nigeria. The site is characterized by a tropical savannah climate with an average annual rainfall of 800 mm and an average temperature of 25°C to 30°C. The soil type in the area is predominantly sandy loam. (Ojanuga, 2006)

Soil Sampling and Preparation

Twenty (20) soil samples were collected from the study area using a Grid pattern by auguring to a depth of 0 to 30 cm to ensure representative sampling across the field. The samples were then air-dried, gently crushed and passed through a 2 mm sieve to remove larger particles and debris. Prepared samples were stored in clean airtight containers until analysis.

Soil Analysis

The soil analysis involved several procedures to assess soil health parameters under the cover crop treatments. Soil pH was measured using a pH meter in a 1:2.5 soil-to-water suspension, following the method described by McLean (1982). The electrical conductivity of the soil was measured in a 1:5 soil-to-water extract to determine the soil's salinity level, following standard methods (Rhoades, 1996) and then converted to Electrical Conductivity of saturation extracted using slavish conversion factor (Slavich and Petterson, 1993). Total nitrogen content was determined using the Kjeldahl method, as outlined by Bremner and Mulvaney (1982). Soil organic carbon was determined using the Walkley-Black wet oxidation method (Nelson and Sommers, 1982) and converted to organic matter using a multiplier of 1.72. Exchangeable bases which are calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were extracted using buffered ammonium acetate, Na and K were quantified flame photometer while Ca and Mg were measured using atomic absorption spectrophotometry (Thomas, 1982). Exchangeable acidity, including aluminum (Al) and hydrogen (H) ions, was determined by titration with potassium chloride (KCl) solution following the method described by Thomas (1982). Cation Exchange Capacity (CEC) was estimated by summing the exchangeable bases and exchangeable acidity as described by Sumner and Miller (1996). Available phosphorus will be measured using the Bray P1 method for acidic soils, as described by Bray and Kurtz (1945).

RESULTS AND DISCUSSION

Fertility Status of Dutsin-Ma Soil

The results presented in Table 1 represent the descriptive statistics of the fertility parameters of Dutsin-Ma soils, which are one of the key indicators of soil health. The result indicates that the soil texture in Dutsin-Ma is predominantly sandy (mean = 50.62%), with moderate proportions of silt (mean = 27.46%) and clay (mean = 21.92%), suggesting a loamy texture that might require managing water and nutrient retention. The pH value is slightly acidic (mean = 5.77), which is generally favorable for maize growth, but the relatively low organic carbon (mean = 0.57%) and total nitrogen (mean = 0.05%) levels indicate that soil fertility could be improved. The low organic carbon content could limit microbial activity, which is essential for soil fertility, while the total nitrogen levels could restrict plant growth and productivity. Available phosphorus (mean = 3.2 mg/kg) is in the moderate range, but it can be further enhanced through improved nutrient cycling. The cation exchange capacity (mean = 3.24 cmol(+)/kg) is moderate, suggesting that the soil has a fair ability to retain essential nutrients. The structural stability index (SSI) of 4.36 indicates moderate soil aggregation,

which can be further improved by the addition of organic amendments (Abdulkadir *et al.;* 2020)
The organic carbon and total nitrogen levels in the soil are relatively low, which could limit soil fertility and plant growth. Soil management practices that can improve soil organic matter will be favourable such as the addition of organic amendment to soil (Abdulkadir *et al*., 2020), use of Cover crops; these cover crops contribute to improving organic matter content in the soil, which is vital for sustaining microbial activity and nutrient cycling (Tadesse *et al*., 2020). Increased organic matter improves the cation exchange capacity (CEC), helping the soil retain more nutrients like phosphorus, potassium, and magnesium, which are crucial for maize growth (Ezeaku *et al.;* 2021; Zhang *et al.;* 2021).

Table 1: Descriptive statistics of fertility parameters in Dutsin-Ma

	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Sand (%)	46.48	57.68	50.62	4.88	1.58	2.90
Silt (%)	21.57	31.60	27.46	4.24	-1.14	1.96
Clay (%)	19.58	24.62	21.92	2.22	0.35	-1.82
pH (1:1)	5.60	5.93	5.77	0.13	-0.10	1.43
O.C (%)	0.34	1.03	0.57	0.32	1.84	3.55
TN (%)	0.04	0.06	0.05	0.01	0.07	-5.53
SSI	2.57	7.24	4.36	2.01	1.46	2.71
P (mg/kg)	0.89	6.65	3.2	2.47	1.11	1.43
Ca (cmol(+)/kg)	1.76	2.67	2.14	0.40	0.83	-.25
Mg (cmol(+)/kg)	0.53	0.83	0.70	0.12	-0.77	1.70
K (cmol(+)/kg)	0.22	0.33	0.27	0.05	0.42	.75
Na (cmol(+)/kg)	0.07	0.12	0.10	0.02	-0.49	-3.18
EA (cmol(+)/kg)	0.002	0.05	0.03	0.02	-0.51	1.04
ECEC (cmol(+)/kg)	2.94	3.57	3.24	0.30	0.22	-3.44

Note: O.C = Organic Carbon, TN = Total Nitrogen, SSI = Structural Stability Index, P = Available Phosphorus, Ca = Exchangeable Calcium, Mg = Exchangeable Magnesium, K= Exchangeable Potassium, Na = Exchangeable Sodium, EA = Exchangeable Acidity and ECEC = Effective Cation Exchange Capacity

Micronutrients Status of Dutsin-Ma Soil

Table 2 presents the levels of key micronutrients in soil from Dutsin-Ma. Zinc (Zn) has a mean value of 4.75 mg/kg, with low variability (Std. Deviation = 0.22) and a slight positive skew. Copper (Cu) averages 2.70 mg/kg, with a higher variability (Std. Deviation = 0.30) and a negative skew, suggesting more frequent lower values. Manganese (Mn) has a mean of 25.50 mg/kg, with a wide range (Std. Deviation = 5.40) and a near-normal distribution. Iron (Fe) averages 116.83 mg/kg, with substantial variability (Std. Deviation = 12.15) and a positive skew. The micronutrient levels in the soil indicate that the use of cover crops like Mucuna, Lablab, and Cowpea may help optimize the availability of these micronutrients, enhancing soil health for maize cultivation.

Micronutrient Levels (Table 2): The levels of essential micronutrients in the soil, including Zinc (mean = 4.75 mg/kg), Copper (mean = 2.70 mg/kg), Manganese (mean = 25.50 mg/kg), and Iron (mean = 116.83 mg/kg), fall within the acceptable ranges for maize production. However, the considerable variability in Iron levels (standard deviation = 12.15) could indicate fluctuations in its availability, which may affect its uptake by maize crops. Such variability could be addressed through the use of cover crops, which have been shown to stabilize micronutrient availability by promoting microbial activity and organic matter decomposition (Khan *et al*., 2020).

Micronutrient Availability: The micronutrient levels in the soil, particularly zinc, copper, and manganese, are within the range that supports maize growth. However, fluctuations in micronutrient availability, especially iron, could be problematic. Cover crops like Mucuna can promote the activity of soil microorganisms that help solubilize nutrients and make them more available to crops (Sharma *et al*., 2020). Furthermore, these cover crops can increase the soil's organic matter content, which not only supports microbial activity but also enhances the chelation of micronutrients, improving their availability to plants (Khan *et al*., 2020). This effect is particularly important in tropical soils where micronutrient deficiencies can often limit crop productivity.

Table 2: Descriptive statistics of micronutrients level in Dutsin-Ma

Heavy Metals	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Zn (mg/kg)	4.50	5.00	4.75	0.22	0.04	-1.15
Cu(mg/kg)	2.26	2.93	2.70	0.30	-1.62	2.60
Mn (mg/kg)	18.95	31.41	25.50	5.40	-0.28	-1.31
Fe (mg/kg)	107.52	133.20	116.83	12.15	1.05	-.29

Note: Zn = Zinc, Cu = Copper, Mn = Manganese and Fe = Iron

Salinity Level of Dutsin-Ma Soil

Table 3 presents the salinity parameters in Dutsin-Ma. The mean percentage base saturation (%BS) is 99.21%, indicating high saturation with a low variability (Std. Deviation = 0.55) and a positive skew. Sodium Adsorption Ratio (SAR) averages 0.08, with low variability (Std. Deviation = 0.02) and a negative skew, suggesting more frequent lower values. The Exchangeable Sodium Percentage (ESP) has a mean of 3.04%, with a higher variability (Std. Deviation = 0.95) and a near-normal distribution. Magnesium Hazard (MH) averages 25.00, showing a wide range (Std. Deviation = 5.66) and a negative skew. Electrical Conductivity (EC) has a mean of 0.02 dS/m, with low variability (Std. Deviation = 0.01) and a positive skew. The high base saturation and moderate salinity parameters suggest that cover crops like Mucuna, Lablab, and Cowpea may help improve soil health by reducing sodium accumulation and promoting better nutrient balance in the soil, benefiting maize production.

Salinity Parameters (Table 3): The soil exhibits high base saturation (mean = 99.21%), which indicates that the soil is rich in base cations such as calcium and magnesium. This is generally beneficial for soil fertility and structure. The Sodium Adsorption Ratio (SAR) (mean = 0.08) and Exchangeable Sodium Percentage (ESP) (mean = 3.04%) are both low, suggesting that sodium toxicity is not a significant issue. However, the moderate Magnesium Hazard (mean = 25.00) and Electrical Conductivity (mean = 0.02 dS/m) could indicate a potential salinity issue, although it is not severe. The use of cover crops could help alleviate this potential issue by improving soil structure, increasing organic matter, and enhancing water infiltration, thereby reducing salinity-related stress (Bates *et al.,* 020).

Managing Soil Salinity: The high base saturation and low SAR values suggest that the soil in Dutsin-Ma is not prone to high sodium toxicity, which is beneficial for maize growth. However, the moderate Magnesium Hazard and Electrical Conductivity levels indicate that the soil may be prone to some salinity stress, which can be detrimental to crop growth. Cover crops can help reduce salinity stress by improving soil structure and enhancing water infiltration, thus preventing salt accumulation in the root zone. Mucuna, Lablab, and Cowpea have been shown to improve soil structure by promoting aggregation, which facilitates better water movement and reduces the potential for salt buildup (Bates *et al.;* 2020). Moreover, the addition of organic matter from these cover crops can also help buffer against soil salinity by improving the soil's physical properties and enhancing its overall health (Sharma*t al.;* 2020).

Table 3: Descriptive statistics of Salinity Parameters in Dutsin-Ma

	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
%BS	98.60	99.93	99.21	0.55	0.60	1.62
SAR	0.06	.10	0.08	0.02	-0.25	-4.58
ESP	2.03	3.89	3.04	0.95	-0.14	-5.15
MH	16.66	29.23	25.00	5.66	-1.79	3.42
EC(dS/m)	.01	0.03	0.02	0.01	0.86	-1.29

Note: %BS = Percentage Base Saturation, SAR = Sodium Adsorption Ratio, ESP = Exchangeable Sodium Percentage, Magnesium Hazard and EC = Electrical Conductivity

CONCLUSION

This research assessed the soil health status of Dutsin-Ma, Katsina State, the results indicate that the soil is predominantly sandy loam with a slightly acidic pH, moderate levels of available phosphorus, and low organic carbon and total nitrogen content. These findings suggest that while the soil has potential for agricultural productivity, its fertility is limited by low organic matter and nitrogen levels, which may hinder microbial activity and nutrient cycling. The micronutrient analysis showed that zinc, copper, manganese, and iron were within acceptable ranges for crop growth, though iron availability exhibited variability, potentially affecting plant uptake. Salinity parameters indicated high base saturation and low sodium adsorption ratios, suggesting a generally favorable soil environment. However, moderate magnesium hazard and electrical conductivity values highlight potential risks of salinity stress over time. To improve soil fertility and sustain agricultural productivity, integrated soil management practices such as the application of organic amendments, cover cropping, and balanced fertilization should be adopted.

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