Assessment of Soil Properties in Two Agro Ecological (Sudan and Sahel Savannah) Zones of Yobe State for Improved Agricultural Productivity

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Abstract

Agricultural practices require sustainable use and management of soil resources while maintaining soil quality. Soil degradation remains a global environmental phenomenon caused by anthropogenic activities. The assessment of soil properties in some selected land uses of two agro ecological zones (Sahel and Sudan Savannah) of Yobe state was carried out. Soil samples from three land uses were collected from 0-30 cm depths (forest, cultivated and fadama land). The soil samples were labeled, air dried, crushed, sieved through a 2 mm mesh and subjected to various physical and chemical analysis. Descriptive statistics and soil degradation was done using standard procedures. The level of degradation of soils were assessed using standard indicators and criteria for land degradation assessment by global assessment of land degradation. Analytical data from each sample were placed in a degradation class by matching the soil characteristics with the land degradation indicators, while estimation of the overall degree of degradation was arrived at mathematically, using physical, chemical and biological parameters. The results show that the textural class of the soil ranged from clay to sandy loam. Permeability ranged from 0.13 to 8.01 cmhr^{-1} corresponding low to high permeability. Bulk density ranged from 1.25 to 1.65 gcm^{-3}. Organic matter was very low in all the sites. Available phosphorus ranged from 6.33 to 15.8 mgkg$^{-1.}$ Total nitrogen was predominantly low (0.06-0.09%) in all the land uses. Exchangeable sodium percentage (ESP) of the sites depicted that most of the soils were non sodic soils (0.80-1.70%). The potential for all the land uses were moderately degraded from fadama land (42.12%), cultivated land (45.0%) and forest land (49.50%) respectively. The major barriers in the study areas were low fertility and soil conservation measures. In order to improve crop production in these areas, there is need to introduce soil conservation measures such as, applying farm yard manure, compost, crop residues or poultry manure to boost soil fertility. Regular monitoring of the fertility status of the soil is encouraged.

Keywords: *Agro-ecological zones, Soil Properties, Land degradation, Soil fertility*

Introduction

Agricultural practices require sustainable use and management of soil resources (Talha and Abba, 2019). The soils may easily lose their nutrients and qualities within a short period of time under poor management and land use (Yakubu, 2010). Soil, being the natural medium for plant growth, has a direct impact on yield and quality of crops and pastures growing on it. Improving the productivity of the agricultural sector of the country is greatly dependent on efficient utilization and management of soils (Musa and Salem, 2020). Soils in many areas have been degraded irreversibly and has become incapable for supporting agricultural production. Spatial variability of physio-chemical characteristics concerns on the evaluation of the factors such as climate, and physio- chemical characteristics of soil (Roslan *et al.*, 2011).

Soil properties describe the physical and chemical characteristic behaviour of soils (Usman, 2017) which all together entails its fertility. The need for basic knowledge and assessment of changes in soil properties and their fertility status with time to evaluate the impact of various soil management practices has become necessary for sustainable agriculture in Nigerian savanna zones (Usman, 2020). Similarly, for sustainable soil nutrient management in these zones, there is also need for an understanding of how soil responds to agricultural practices over time.

Knowledge of soil properties in the savannah describe the inherent soil productivity and fertility to support crop production which should be evaluated for changes over time as a result of adverse weathers in the tropics. Soil fertility is a complex soil index which include physical and chemical characteristic, and it is an important component of overall soil productivity (Talha and Abba, 2019). Soil fertility institute availability of nutrient status, and its aptitude to provide nutrients out of its own reserves and through exterior applications for crop production (Reddy, 2013). According to report by Wang et al. (2018), soil fertility degradation is aided more by climate change and described it as one of the most important constraints to food security. Soil fertility degradation implies a decline in soil quality with an attendant reduction in ecosystem functions and services (Lal, 2015).

Adverse changes under high temperatures and heavy rainfall have resulted to highly diversified soils in the tropics. Consequences of this brought about degradation of soil physical and chemical qualities and thus, limit the productivity of the soils in the regions. However, continuous research cycle largely focused on agronomic, with very little attention given to the soil fertility status of the farms. This resulted to scarcity of soil data and has always demanded a supplemental source of soil nutrients (organic or inorganic). The use of chemical fertilizers in supplementing the soil requirement has been increasing steadily, however, sustainable agricultural productivity depends largely on improved soil fertility management and hence, according Talha and Abba (2019), considered an important factor in production. Soil analysis or test is a reliable tool used in evaluating and predicting the fertility condition of a soil, thus employed as a diagnostic tool for management strategies in improving soil fertility for increased production. Therefore, this research will evaluate soil properties of the selected areas of Yobe State for improved agricultural productivity.

Materials and Methods

The research was carried out in two agro-ecological zones (Sudan and Sahel Savannah) of Yobe state, Nigeria, on three land uses (Cultivated, Fadama and Forest); which is located between latitude 13° 15' 14" N and Longitude 10° 55' 41" E with elevation ranging from 314 to 311 meters above sea level. The annual temperature varied between 33ºC and 41ºC and an annual rainfall in the study area varied from 45.46mm to 48.46mm. The economic activities of local communities of the study area are mixed farming systems (maize, millet, sorghum, rice, cowpea, soybeans, groundnuts, Bambara nut and vegetable crops etc.)

Soil Sampling and Preparation

Two composite samples for disturbed soils and soil cores were collected for the measurement of permeability (Ks)(cm hr) and the bulk density (BD)(g/cm^3) depth using a soil auger in all the three land uses respectively. The soil samples were labelled, air dried, crushed, sieved through a 2 mm mesh and subjected to physical and chemical analysis. Particle size analysis was determined using the Bouyoucos hydrometer method (Brady and Weil, 2017). The cylinder cores were linked to a Mariotte's bottle to measure the Ks using the constant head method based on Darcy's law.

Soil pH was measured in a 1:2.5 soil-water ratio suspension while electrical conductivity (EC) w as determined using a conductivity meter in a soil- water extract method (Rowell, 1994). Organic c arbon was determined by the wet digestion method as described by Walkley and Black (193 4) and the content of organic matter was obtained by multiplying organic carbon content by a facto r of 1.724. Micro-Kjeldahl digestion, distillation and titration method was used to determine total nitrogen as described by Akinremi *et al.* (2003). Available phosphorous was analyzed using Bray 1 method using .03 M NH_4F and 0.10 M HCl solution according to Bartlett *et al*. (1994). Catio n exchange capacity (CEC) and exchangeable Ca, Mg and K were extracted with 1 M NH_4OA c at pH 7 by which exchangeable Ca and Mg in extracts were analyzed using atomic absorption spectrophotometer while K by flame photometer (Agbenin, 1995), base saturation percentage (BS P) and exchangeable sodium potential were duly computed. Exchangeable cations (Ca, Mg, K, Na) were determined by the NH4oAC method as described by Agbenin (1995). Cation exchange capacity (CEC) was determined by the NH_4OAC extraction method of Rhoades (1982), base saturation percentage (BSP) and exchangeable sodium potential were duly computed.

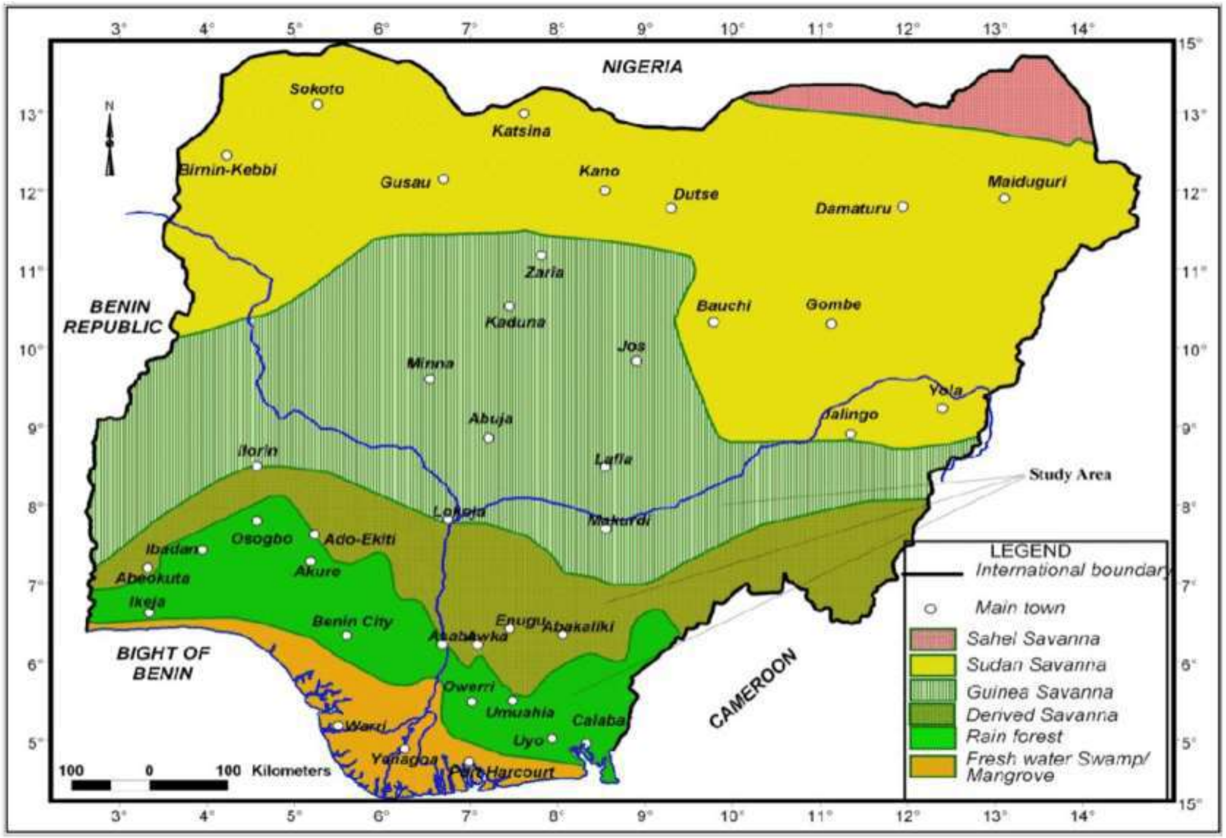

Figure: Map of Nigeria showing agro ecological zones (Hakeem *et al.*, 2020)

Soil degradation assessment

Soil degradation was assessed using the standar d indicators and criteria for land degradation assessment outlined by the Global Assessment o f Land Degradation as indicated in Table **1a** and **1b** (GLASOD, 1998). Analytical data from each sample were placed in a degradation class by matching the soil characteristics with the lan d degradation indicators, while estimation of the overall degree of degradation (ODD) was arrive d at mathematically, using physical, chemical, and biological parameters as shown in equation 1 below:

$$ODD = \frac{\Sigma Degree\ of\ degradation\ of\ each\ quality}{ax.degree\ of\ degradation\ x\ Number\ of\ qualities} \text{ x } 100$$

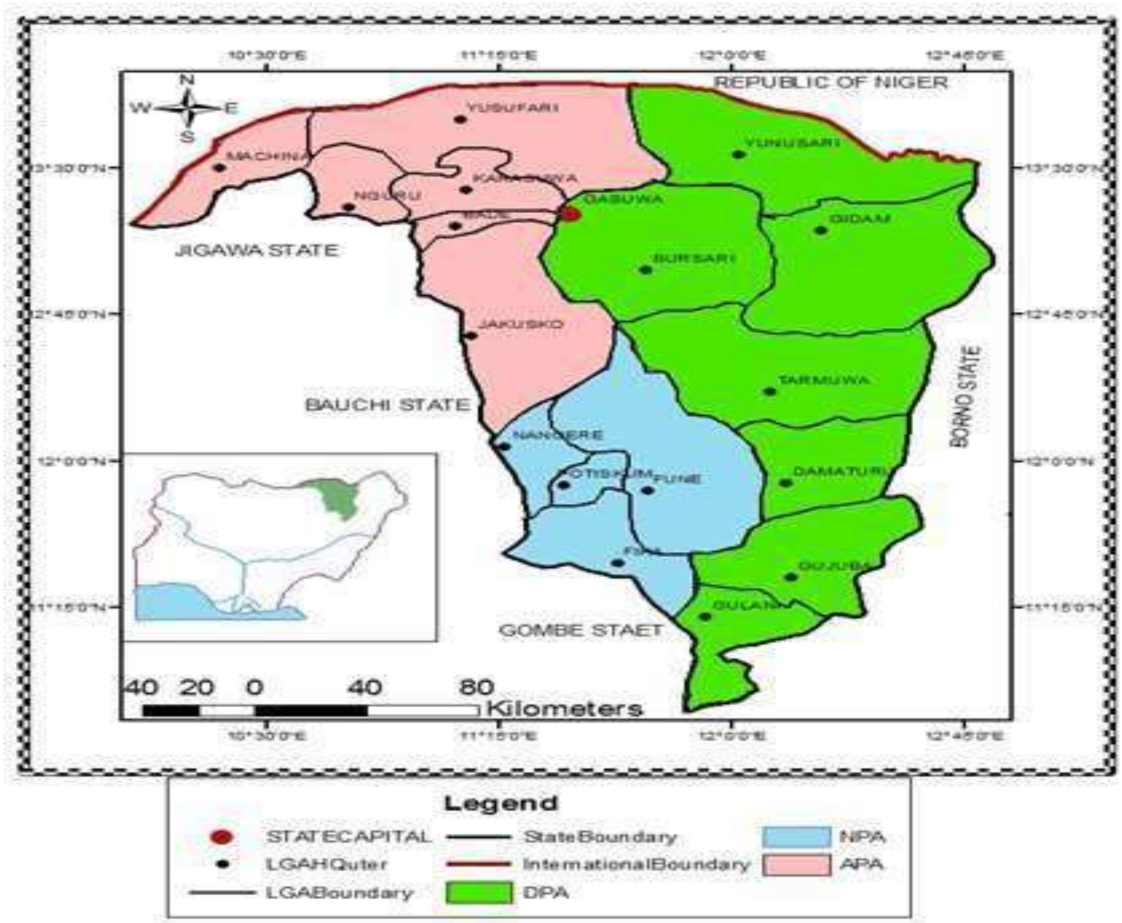

Figure: Map of Yobe state showing plantation zones

Data Analysis

All data obtained from the laboratory analysis were subjected to Analysis of variance (ANOVA) using Statistical Package for Social Sciences (SPSS) v. 25.

RESULTS AND DISCUSSION

Physical degradation

The results of soil physical and chemical properties obtained from the research were presented in 2 and 3 while degradation scores for each indicator an d overall degradation rating were shown in Table 4.

Particle size distribution from different land use indicated different textural classes. Although textural classes are one of the intensive properties of the soil that is not easily affected by management practices or land use, which are rat her permanent and often used to characterize the soil's physical make-up (Agbai and Kosuowei, 2022). The soils in the Fadama land had higher Clay content compared with the cultivated land (Table 2). This is in line with the observation of Ibrahim *et al.* (2021b) who deduced that clay-rich Fadama land has been continually affected by problems of inadequate aeration, waterlogging, i ncreased run off as well as erosion, and workability problems during dry and wet periods. The texture of the soil has a high influence on the physical and chemical propertie s of the soil which are used as a quality indicator for soil quality assessment. An average bulk den sity of 1.25 and 1.50 mg/m^3 (< 1.5 mg/m^3) was o btained from the forest and cultivated land and t his ranged from none to slightly degraded conce rning bulk density, Fadama land with an average value 1.65 mgm^{-3} (1.5 - 2.5 mgm^{-3}) were moderately degraded. It is however worthy of no te that the bulk densities of the three land use (both the cultivated, forest and Fadama land) were less than the critical limits for root restriction (1.75–1.85 g/cm^3) as reported by soil survey staff (199 6). The loss of SOM by the conversion of the forest into cultivated fields probably caused a higher bulk density in the cultivated soils (Ibrahim *et al.*, 2021b). According to Awwal *et al*, (2020), the bulk density of soil affects compaction, root growth, and water retention wi thin the soil, while Schoenholtz *et al.* (2000) opined that changes in bulk density affect other properties and processes that influence water and oxygen supply. However, Brady and Weil (2017) linked bulk density to soil texture, structure, and organic components. Oyedele *et a l.* (2009) opined that cultivation has been noted to increase bulk density. Fadama land was none to slightly degraded soils compared to cultivated soil which were moderately degraded in terms of per meability, while forest land was highly degraded concerning the degradation scores as shown in Table 3. This meant that Fadama land may retain more moisture than cultivated and mining land. Awwal *et al.* (2020) indicated that there is an inherent relationship between bulk de nsity and permeability (Ks). The permeability of soils is also affected by soil texture, structure, an d porosity

Table 1a: Indicators and criteria for land degradation assessment

Indicator	Degree of degradation			
	1	2	3	4
Physical degradation				
Soil bulk density (mgm^{-3})	<1.5	1.5 - 2.5	2.5 – 5	>5
Permeability	<1.25	1.25 – 5	5 – 10	>20
Chemical degradation				
Content of N element (multiple decrease) N (%)	>0.13	0.13 – 0.10	0.10 – 0.08	<0.08
Content of phosphorus element (mg kg^{-1})	> 8	8 - 7	7 – 6	< 6
Content of phosphate element (Cmol(+) kg^{-1})	>0.16	0.16-0.14	0.14 – 0.12	< 0.12
Content of ESP (increase by 1% of CEC)	< 10	10 – 25	25 – 50	>50
Base saturation (decrease of saturation in more than 50%)	<2.5	2.5 – 5	5 – 10	>10
Excess salt (salinization)(increase of conductivity mmho cm^{-1} yr^{-1})	<2	2-3	3-5	>5
Biological degradation content of humus in soil (%)	>2.5	2.5-2.0	2.0-1.0	>1.0

Source: FAO (1979), GLASOD, (1998); Snakin *et al.* (1996).

Table 1b: class of degradation

Class of degradation	Overall degree of degradation (%)	Description
1	0-25	None to slightly degraded
2	26-50	Moderately degraded
3	56-75	Highly degraded
4	76-100	Very highly degraded

The value of 1 shows minimal degradation while 4 represents an extreme range of degradation

Table 2: Particles size distribution of soils of the study area

Land use	Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	texture
Forest land	860	80	90	Loamy sand
Cultivated land	660	200	130	Sandy loam
Fadama land	360	190	480	Clay

The value of 1 shows minimal degradation while 4 represents an extreme range of degradation

Table 3: Soil quality (QI) indicators for soil degradation assessment

Land use	Bulk density (mgm^{-3})	Permeability ($cmhr^{-1}$)	Total nitrogen (%)	Available phosphorus ($mgkg^{-1}$)	Exch.K (Cmol(+)kg^{-1})	ESP (%)	EC (dSm^{-1})	Percent base saturation (%)	Organic matter (%)
Forest land	1.25	8.01	0.09	6.3	0.51	1.70	0.45	60.6	1.91
Cultivated land	1.50	2.06	0.06	10.05	1.91	1.06	0.43	60.8	1.05
Fadama land	1.65	0.13	0.07	15.8	1.77	0.8	1.10	60.8	1.21

Table 4: Degradation scores for the various studied soils.

Land use	Forest land	Cultivated land	Fadama land
Physical Degradation			
Soil bulk density (mgm^{-3})	1.00	1.00	2.00
Permeability ($cmhr^{-1}$)	3.00	2.00	1.00
Chemical degradation			
Content of N element (multiple decrease) N (%)	4.00	4.00	4.00
Content of Phosphorus element (mg kg^{-1})	3.00	1.00	1.00
Content of Potassium element (Cmol(+)kg^{-1})	1.00	1.00	1.00
Content of ESP (increase by 1% of CEC)	1.000	1.00	1.00
Base saturation (decrease of saturation in more than 50%)	1.00	1.00	1.00

Excess salt (salinization)(increase of conductivity mmho/cm/yr)	1.00	1.00	1.00
Biological Degradation			
Content of humus in soil (%)	3.00	4.00	3.00
Overall degradation index	49.50%	45.0%	42.12%

Chemical degradation

The result of the chemical degradation of the soils is presented in Table 3. The percentage of the nitrogen content of the soils was highly degraded in all the land uses. The content of nitrogen as shown in Table 3 indicates a low availability of Nitrogen as per the Esu (1991) rating scale. This might be a reflection of the soil amendment strategies employed by farmers.

Generally, the low nitrogen (N) content recorded in this research might be attributed to the high rate of nitrogen (N) mineralization and loss of organic matter content in the soils (Senjobi and Ogunkunle, 2011). The use of organic mulches and proper management practice such as discouraging the removal of crop residues (stubbles) by farmers should be employed to manage the rate of nitrogen degradation and loss in these soil (Ewetola *et al.*, 2015). Nitrogen is a key nutrient element of soil quality indicators and is a basic component of many physiological processes in plants (Ananya *et al.*, 2019; Ibrahim *et al.*, 2018). Agbede (2009) reported that Nitrogen (N) is the most important constituent element needed for plant growth, development and reproduction. Ewetola *et al.* (2015) and Ibrahim *et al.* (2022) opined that N is the most limiting nutrient element especially, in the tropics where organic matter decomposition is rapid and nitrogen released from the process is easily lost through leaching or evaporation. Fadama and cultivated soils were highly degraded while forest was none to slightly degraded soils concerning the content of phosphorus. The generally low values of available phosphorus in the soils indicated the need for the application of phosphorus to the soils for optimum crop production. Conversely, all three land uses were none to slightly degraded soils concerning the content of potassium element and values were greater than 0.16 (Cmol (+) /kg), exchangeable sodium percentage (ESP), base saturation percentage (BSP), and electrical conductivity (EC). Amongst others, this is a good indication that the soils had none to very slight salinity and sodicity threat. The degradation indices ranged from 49.50 % for ESP, BSP and EC for forest land, 45.0 % for ESP, BSP and EC for cultivated land to 42.12% for ESP, BSP and EC for fadama land.

Biological degradation

In terms of humus content of the soils, Fadama and forest land soils were highly degraded, where values fell below 2.0% while cultivated soils were very highly degraded (<1.0%) (Table 3). This is an indication of very high biological degradation which is typical of Sudan savannah soil.

Very low organic matter (OM) recorded in this research is indicative of very high biological degradation of all the soils of the study areas. The results obtained corroborate the findings of Stevenson and Cole (1999) who deduce that cultivation of natural land resources induces SOM losses, which in turn directly affects the soil's chemical, physical, and biological properties, finally resulting in loss of crop production capacity. The OM depletion might be due to crop uptake exacerbated by continuous cropping without adequate measures for nutrient replacement either through the use of inorganic fertilizer or other forms of soil conservation measures. Degradation and low hu mus content in savanna soils have been reported by several researchers (Raji *et al.,* 1995; Odunze , 1998; Ibrahim *et al.,* 2010; Ibrahim and Umar, 2012; Maniyunda, 2012). However, the loss rate of humus is noted to be higher in cultivated soils than Fadama, forest land soils. Ashenafi *et al.* (2010) attributed the higher loss of humus in cultivated soils to the fact that cultivation acc elerates the depletion of organic matter content in soils. Land use practices such as bush burning w hich is very rampant in the savanna ecosystem might be partly accounted for the destruction of OM content and even the microbial populace in the soils. To protect these soils from further biol ogical degradation, conservation tillage and proper management of organic wastes should be employed (Awwal *et al.,* 2020).

Overall degradation

The result of the overall degradation rate of the soils are presented in table 3. The overall degradation rate indicates that all three land uses soils were moderately degraded (forest land 49.50%, cultivated land 45.0% and fadama land 42.12%) in the respective agro-ecological zones. This corroborates earlier reports that over cultivation may lead to the depletion of soil qualities (Oyedele, *et al.,* 2009; Ande and Senjobi, 2014).

Conclusion

An investigation into soil properties was conducted to assess the degree of degradation and properties of the soils in some selected land uses of two agro ecological zones of Yobe state. The study revealed that most of the soils (about 50%) were moderately degraded, even though, those of the forest land that would have been expected to be better shows signs of serious degradation. So for improved agriculture due to the research, inorganic fertilizer need to be applied on the lands to improve Nitrogen, phosphorus and potassium. Also to increase productivity of the degraded soils incorporation of legumes, compose and poultry dropping is encouraged.

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