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THE EFFECT OF LAND USAGE AND DEPTH ON SOIL QUALITY IN NORTHERN NIGERIA'S SEMI-ARID REGION

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ABSTRACT

Soil quality is a critical factor in determining agricultural productivity, ecosystem sustainability, and land management efficiency. Soil quality indices evaluation was based on the soil management assessment framework (SMAF) a minimum set of data, which is the smallest set of soil properties or indicators needed to measure soil quality, identifying key soil properties or attribute that are sensitive to change in soil functions established a minimum data set More is better, less is better, Optimum is better When cumulatively put together however, acacia vegetation soil had the highest score index followed by native vegetation soil, then arable land with least in bare land, for the depth, 40-60cm is higher than 0-20cm with least been 20-40cm.when cumulatively put together, the variation order of soil is (acacia > native > 40-60cm depth>0-20cm>20-40cm>arable >bare land) indicate the direction of good quality of soil. Soil quality was assessed using a score scale of 1 to 6; where 1 is rated best and 6 rated worst. Thus; acacia with highest total score was rated best, while bare land with lowest total score rated worst. Acacia scored best and enhance soil quality conditions (optimum soil organic carbon, total nitrogen, available phosphorus, potassium, EC, and bulk density), while bare land was rated worst (low organic carbon, low k, moderate phosphorus, moderate nitrogen, low bulk density and electrical conductivity

INTRODUCTION

Soil quality is a critical factor in determining agricultural productivity, ecosystem sustainability, and land management efficiency (Andrews *et al*. 2004). In northern Nigeria's semi-arid region, soil quality is influenced by various factors, including land use practices and soil depth (Andrews *et al*. 2001). Different land use systems such as agriculture, grazing, and fallow land affect soil properties by altering organic matter content, nutrient availability, and microbial activity. Similarly, soil depth plays a significant role in soil quality, as surface layers typically contain higher organic matter and nutrients compared to deeper layers (Andrews *et al*. 2001).

However, unsustainable land use practices, such as overgrazing, deforestation, and continuous cropping, have led to soil degradation, reducing soil fertility and increasing erosion risks (Larson and pierce, 1994). Understanding how land use and soil depth interact to influence soil quality is essential for developing sustainable land management strategies. This study aims to examine the effect of land usage and depth on soil quality in northern Nigeria's semi-arid region, providing insights for improving soil conservation and agricultural productivity.

The semi-arid region of northern Nigeria is characterized by low soil fertility, erratic rainfall, and high susceptibility to degradation. As population growth and food demand increase, land use practices have intensified, often leading to soil depletion and reduced productivity. However, there is limited research on how different land use types and soil depths collectively influence soil quality in this region (Larson and pierce, 1994). A better understanding of these interactions is crucial for developing sustainable agricultural practices and soil management strategies. By analyzing soil quality variations under different land uses and depths, this study will provide essential data for policymakers, farmers, and environmental planners to adopt land management practices that enhance soil fertility, prevent degradation, and improve overall land productivity.

Soil degradation is a major challenge in northern Nigeria's semi-arid region, largely due to unsustainable land use practices and poor soil management (Anikwe 2006). Intensive farming, deforestation, and overgrazing have contributed to declining soil quality, reducing agricultural yields and threatening food security. Furthermore, variations in soil properties with depth remain poorly understood, making it difficult to implement effective soil conservation strategies (Anikwe 2006). Despite the importance of soil depth in nutrient distribution and organic matter retention, there is a lack of comprehensive studies examining how different land use systems interact with soil depth to affect soil quality in this region. Without this knowledge, land degradation will continue to escalate, leading to further declines in productivity and environmental sustainability (Anikwe 2006). This study seeks to address these gaps by evaluating the effects of land use and soil depth on soil quality in northern Nigeria's semi-arid zone. The findings will provide valuable insights into soil conservation strategies, helping to improve land use planning and ensure long-term agricultural sustainability.

MATERIALS AND METHOD

Site description

The study area is Barema farm, established in year 2002 situated some 11 kilometers away from Damaturu, Tarmuwa Geidam road and it cover about 15 square kilometers. The area lies between Latitude 11.8563618$^{0'}$N and Longitude 11.891489^{0} E, with varying altitude varied from 426 to 433 above sea level. the climate of the study area is tropical wet and dry type (Adamu 2012 and Hamza 2018) with annual rainfall of about 500- 760mm all fall withing may-June to October, and mean temperature range 25 to 30^{0} c (Ojanuga, 2006). the soils are mostly moderately deep and well drain sandy loam textured surface and sandy clay loam subsoil (Hamza 2019) the farm is situated in Sudan-Sahel Savannah vegetation type composed of shrubs and grasses with scattered trees. According to the USDA Soil Taxonomy, soils can be classified as Alfisols, this area is dominated by degraded Native vegetation dominated by grass and shrub species; such as *Piliostigma reticulatum, Daniellia oliveri and Guera senegelensis* After clear-cutting in some areas of degraded natural forests, about 20 years ago, the area was reforested with acacia species (within 2 × 2 m spaces). The stands were never fertilized. However, some areas were not afforested and are now converted to other land uses/covers (Adamu 2012 and Hamza 2018). A detailed description of each site is reported in figure 1

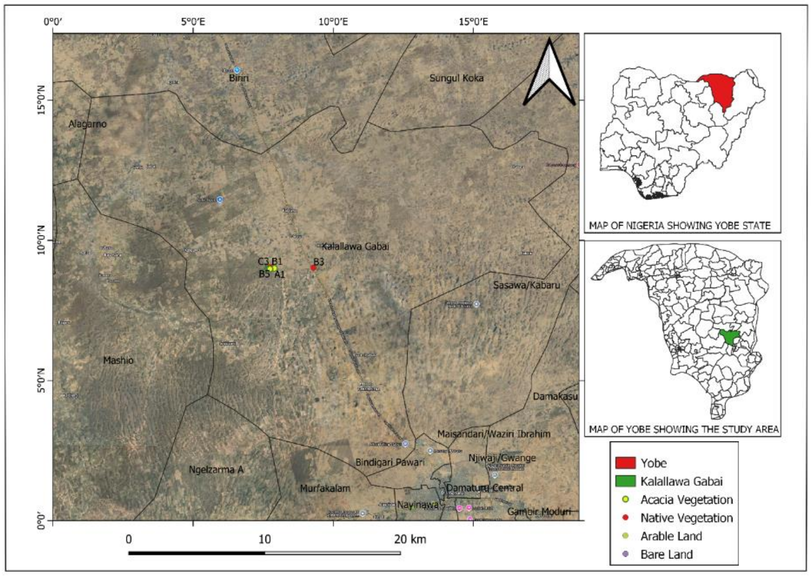

Figure 1: map of yobe state showing the study area

For the non-profile determinations, sample collected by auguring from 0-20, 20-40, 40-60, 60cm soil depths disturbed and undisturbed core samples, (4 land use x 3 depth x 6 replicates = 72 soil samples) followed by profile descriptions according to (FAO 2006). Samples for bulk density and hydraulic conductivity was taken from the land uses at depth using core samplers.

Laboratory Methods

The samples were air-dried, gently crushed using a wooden mortar and pestle and then sieved through a 2mm mesh. The sieved samples were stored for chemical and physical analyses. Bulk density was determined by the core sampler method described by Blake and Hartge (1986). Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986) Particle density was determined by the use of Pycnometer bottle method (Blake, 1965). Total porosity was calculated from particle and bulk densities using the relationship P=100 (1-Bd/Pd), where P= porosity, Bd = Bulk density, Pd= Particle density and 100 and 1 are constants. Soil pH (1:1) in H20 and $CaCl_2$ were determined using glass electrode pH meter (Bates, 1954). Organic carbon content of the soils was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). Total nitrogen was determined by the Macro-Kjeldahl digestion and distillation procedures as described by Bremer (1965). Available P was determined by Bray No. 1 Method (Bray and Kurtz, 1954). Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil was determined using the ammonium acetate extract from the CEC determination. Sodium and K were determined using flame photometer and Ca and Mg were determined using atomic absorption spectrometer while Percentage base saturation was calculated by dividing the total exchangeable cations (Ca, Mg, K, and Na) by the cation exchange capacity (CEC) obtained by the 1M NH_4AOC (pH 7.0) as defined by this relationship;

$$BS\% = \frac{\text{Total exchangeable bases}}{\text{CEC (NH4OAC)}} \text{ x } 100$$

Evaluation of Soil Quality Indices

Soil quality indices evaluation was based on the soil management assessment framework (SMAF) suggested by Andrews *et al.* (2004), A general guideline was use of minimum of five indicators with at least one each for biological, chemical and physical properties (Karlen *et al.*, 2011).as suggested by Larson and pierce (1992); a minimum data set (MDS) was established. The MDS to be selected in this study include soil functions such as ease of tillage, salinity support for plant growth, bulk density (BD), CEC, total N, available P, and exchangeable K was used as indicators for plant growth support, while organic carbon was used as indicator for biological activity in the soil and MWD to assess erodibility of the soils. Indicators was divided into two: more is better was applied to N, P, K and organic matter, while less is better which applied to bulk density (Larson and pierce (1992).

Indexing Soil Quality Indicators

This is due to temporal and variability of soil, complexity of an ecosystem and differences in soil management practices available. Andrews *et al.* (2001) postulated that once the system s management goal are identified, soil quality indexing involve three main steps:

i. Choosing appropriate soil quality indicator for minimum data set

ii. Transforming indicators score

iii. Combining indicators the scores into the index.

Choosing Appropriate Soil Quality Indicator for Minimum Data Set

The important step in indexing soil quality indicators is to choose appropriate soil quality indicators to efficiently and effectively capture the effect of critical soil functions as determined by management goal for which the evaluation is being made. Larson and pierce, (1994) proposed a minimum set of data, which is the smallest set of soil properties or indicators needed to measure soil quality, identifying key soil properties or attribute that are sensitive to change in soil functions established a minimum data set

Transforming Indicators Score

This will involve selecting MDS for assessing a particular management objective, that required biological, chemical and physical indicator measurement with totally different measurement unit can be combined and emphasized simplicity on design a linear scoring technique that relies on the observed of data to determine the highest possible score for each indicator

a) More is better: total nitrogen, cation exchange capacity organic carbon content microbial biomass

b) Less is better: bulk density

c) Optimum is better: porosity electrical conductivity, water filled pore space phosphorus, pH, and electrical conductivity Anikwe (2006).

Statistical Analysis

Analysis of variance (ANOVA) test was done to determine significant difference among treatments and factors (land uses and soil depths). In conditions where there was significant difference, mean comparison was performed with least significant difference (LSD) at 0.05% level of probability using statistical analysis software (SAS) SAS, (1997).

RESULT AND DISCUSSION

Effects of land use and depth on soil physical properties

Soil pH (H_2O) and $CaCl_2$

The highest soil pH in water (pH 7.16) 6.1611, 6.2067, 6.1856 and 6.1856 was recorded in acacia, native, arable and bare land respectively. The depth of 0-20cm pH (H_2O) is 6.22, 20-40cm had pH (H_2O) 6.1738 and 40-60cm had pH (H_2O) 6.2188 respectively. Values of soil pH ($CaCl_2$) were 6. 6.0417, 6.1322, 6.0572, and 5.9583 for acacia, native, arable and bare land respectively. surface 0-20cm had pH ($CaCl_2$) 6.0988; 20-40cm had pH ($CaCl_2$) 5.9988 and 40-60cm had pH ($CaCl_2$) 6.0446 values were recorded (Table 1). It however increased slightly down the topographic positions in soils of both cultivated and forested lands. The generally increasing trends in pH value

from subsurface may be due to higher deposition of basic cations in subsurface horizon. This agrees with Belay (1996), Abayneh (2001) and Mohammed *et al.* (2005) who independently reported low pH value in soils of high altitude and steeper slopes are associated with washing out of solutes from these parts. The soil pH range of 6.9 to 7.16 indicates moderately acidic to alkaline soil condition under all the land use systems. Malo *et al.* (2005) also reported that increase in pH with soil depth could be associated with enhanced carbonate levels and less weathering rates. The pH of study soils may also indicate low level of leaching of non-acid cations (Adeboye, 2009).

Particle size distribution

The mean values for sand, silt and clay fractions for forest field were 58.308 %, 57.754 %,

61.149 % and 61.594% for acacia, native, arable and bare land respectively. Upper surface 0-20cm had mean of 60.94 % and 20-40cm has 59.376% while 40-60cm had the lowest sand content (58.787 %), while silt had 27.878 %, 27.545 %, 25.448% and 24.876% acacia, native, arable and bare land respectively while 27.632%, 27.093% 24.586% in the depth of 0-20, 20-40, 40-60cm respectively. clay has the mean of 13.518%, 13.636%, 13.451%, 13.527%, for acacia, native, arable and bare land respectively while 14.460%, 13.392% and 12.747% in the depth of 0-20, 20-40, 40-60cm respectively. with classes as loamy sand texture (Table 1). Particle sizes were not different significantly ($p>0.05$) for the two land uses and depth this suggests that the soil texture was not affected by conversion of forest to cultivated land use and could be prone to leaching due to the high presence of macro-pores of dominating sand fraction that wouldnot affect growth of crops due to low moisture and nutrient retention capacity (Brady and Weil, 2002). Despite the fact that texture is an inherent soil property, management practices may contribute indirectly to changes in particle size distribution particularly in the surface layers as a result of removal of soil by sheet and rill erosions, and mixing up of surface and subsurface layers during tillage activities.

Silt /clay ratio

Silt/clay ratios are relatively higher in acacia land with 2.5858 silt/clay than native with 2.3574 silt/clay ratios fallow by arable with 2.3574 silt/clay ratios and decrease with 2.1869 silt/clay ratios in bare land, surface 0-20cm has 1.9823, silt/clay ratios while 20-40cm increase to 2.3251 silt/clay ratios which increase further with depth to 2.9592 silt/clay ratio (Table 1). Van Wameke (1962) reported that "old" parent materials usually have silt/clay ratio below 0.15, while silt/clay ratios above 0.15 are indicative of "young parent materials. The result of this study shows that, all the soils had silt/clay ratios above 0.15, indicating that the soils had high degree of weathering potentials.

Table 1 Effect of land use and depth on PH (H_2O), PH (cacl$_2$), and particle size distribution

	PH (H_2O)	PH(cacl$_2$)	Sand %	Silt%	Clay%	Silt/clay
Land use						
Acacia	6.1611^{a}	6.0417^{ab}	58.308^{a}	27.878^{a}	13.518a	2.5858^{a}
Native	6.2067^{a}	6.1322^{a}	57.754^{a}	27.545^{a}	13.636a	2.5587^{a}
Arable	6.1856^{a}	6.0572^{ab}	61.149^{a}	25.448^{a}	13.451a	2.3574^{a}
Bare	6.2633^{a}	5.9583^{b}	61.594^{a}	24.876^{a}	13.527a	2.1869^{a}
Significant level	Ns	**	Ns	Ns	Ns	Ns
SE	0.0826	0.0409	1.6281	1.9345	0.8769	0.4303
Depth						
0-20	6.2200^{a}	6.0988^{a}	60.941^{a}	27.632^{a}	14.460^{a}	1.9823^{a}
20-40	6.1738^{a}	5.9988^{a}	59.376^{a}	27.093^{a}	13.392^{a}	2.3251^{a}
40-60	6.2188^{a}	6.0446^{a}	58.787^{a}	24.586^{a}	12.747^{a}	2.9592^{a}
Significant level	Ns	Ns	Ns	Ns	Ns	Ns
SE	0.0715	0.0354	1.4100	1.6753	0.7594	0.3727
Land use *depth	Ns	Ns	Ns	Ns	Ns	Ns

Effect of land use and depth on chemical properties

Electrical conductivity (EC)

Electrical conductivity values were 0.11 dS/m, 0.09 dS/m, 2.31 dS/m, and 0.13 dS/m in acacia, native, arable and bare land respectively. Electrical conductivity was significantly affected by land use though statistically not different by the depth. Electric conductivity at 0-20cm had the mean of 0.72 dS/m; 20-40cm had 0.63 dS/m and 40-60cm has 0.64 dS/m respectively. Electrical conductivity (EC) below 0.75 dS/m is considered low; 0.75–4 dS/m is medium and above 4 dS/m is considered high (McCulley *et al*, 2005). Arable land had high electrical conductivity value, compare to other land uses but show decreasing trend in soil EC down the depth (Table 2). Soluble cations and anions also moved down the depth with surface runoff and accumulate at the bottom profile. The work of other researchers (Putman *et al*., 1987; Ahmad and Khan, 2009) confirmed increase in EC with depth, which they presumed was due to downward movement of soluble ions (Na+, K+, Mg^{2+}, Cl-, and HCO3-).

Organic carbon (OC)

Organic carbon (OC) concentration varied under the different land use systems was 5.6389 g kg^{-1}, 4.9111 g kg^{-1}, 3.0389 g kg^{-1}, and 0.9556 g kg^{-1}, for acacia, native, arable, and bare land respectively. Surface 0-20cm had mean of 3.8408g kg^{-1}, while 20-40cm had 3.3200 g kg^{-1}, and 40-60cm had 3.7475 g kg^{-1} respectively (Table 2). The organic carbon in forestland might be due to accumulation of plant roots, deposition of plant litter and limited soil disturbance that aided accumulation of organic carbon. Other findings corroborating this report include Odunze (2006), who observed highest organic carbon in forest soil, followed by lowest under agro-ecosystems. Conversion of forest ecosystem to other forms of land cover may decrease stock of OC due to changes in soil moisture, temperature regimes and succession of plant species with differences in quantity and quality of biomass returned to the soil (Offiong and Iwara, 2012).

Total nitrogen

Total N contents were highly affected by the different land use systems. Total soil nitrogen at had mean of 0.5389, 0.5167, 0.4833, 0.4722 g kg^{-1} for acacia, native, arable and bare land respectively while 0.5083 g kg^{-1}at 0-20cm, 0.4958 g kg^{-1} for 20-40cm depth and 40-60cm record 0.5042 g kg^{-1} of nitrogen respectively (Table 2). Iwara *et al*. (2011) reported that presence of dense vegetation affords the soil adequate cover, thereby reducing loss in macro and micro nutrients that are essential for plant growth and energy fluxes. The total nitrogen status was low in arable and bare land and high under acacia and fellow native vegetation land in Barema northern guinea savanna of Nigeria. Ayoubi *et al*. (2011) reported that natural forest soils had more total nitrogen compared to cultivated lands. Heluf and Wakene (2006) reported highest total N on surface soil layers of virgin lands compared to arable land fields Total nitrogen decreased consistently with depth under land use systems corresponding to the findings of Gong *et al*. (2005), Geissen and Guzman (2006) and Alemayehu (1990).

Available phosphorus (AP)

Available phosphorus (AP) concentration of land use systems had mean values of 5.7833 mg kg^{-1}, 5.8989 mg kg^{-1}, 5.0711 mg kg^{-1} and 4.2211mg kg^{-1} and 5.47 mg kg^{-1} for acacia, native arable and bare land respectively. Depth distribution of available phosphorus recorded 5.3396 mg kg^{-1}, 5.2763 mg kg^{-1} and 5.1150 mg kg^{-1} for 020cm, 20-40cm, and 40-60cm respectively (Table 2). the land use was significantly affected as ($p < 0.05$). Thomas (2000) reported that natural acacia vegetation contained relatively higher concentration of AP as a result of high organic matter turnover in soils, which released phosphorus during its mineralization and is in conformity with findings from this study. The difference in available phosphorus might be due to increased clay and reduced organic matter concentration in cultivated land.

Carbon/Nitrogen ratio

In this study, carbon to nitrogen (C/N) ratio was affected by land use systems. Consequently, the ratio was lower in soils of bare lands with 1.905 C: N ratio fellow by arable land with 6.198 when compared with acacia land with 11.012 C: N ratio and native vegetation with 10.559 C: N ratio. Depth distribution had 7.8495, 6.7693 and 7.6372 of carbon nitrogen ratio for 0-20cm 20-40cm and 40-carbon nitrogen ratio respectively (Table 2). This is in agreement with Seeber and Seeber (2005), who reported that cultivation alters humus content and thus narrows the C/N ratio. Such differences in C/N ratios among land use systems may also reflect variations in qualities of organic residues entering the soil organic matter pool and could be attributed to contrasting vegetation covers. Caravaca (2002) found lower C/N ratios in arable fields than uncultivated soils and ascribed the higher C/N ratios to input of relatively recent materials of plant or microbial origin in non-cultivated soils. The present study is also in agreement with findings of Odunze (2006), which reported greater C/N ratios in forest soils than agricultural soils. Similarly, Raji and Ogunwale, (2006) reported higher C: N ratio in forest soil as compared to soils under cultivation and pasture.

Exchangeable acidity

The level of exchangeable acidity, Acacia lands recorded EA value of 0.5489 cmolkg^{-1} while native has 0.5872 cmolkg^{-1} which is higher compared to arable with 0.4428 cmolkg^{-1}, with bare land record slightly higher with 0.5333 cmolkg^{-1} while 0—20cm has 0.4600, while 20-40cm has 0.4908 cmolkg^{-1} were EA increase with depth of 0.6333 cmolkg^{-1} in 40-60cm respectively (Table 2). There were generally the decrements on the value of exchangeable acidity with the increment of the depth of soils in study area. Exchangeable acidity, primarily due to the presence of exchangeable aluminum (Al^{3+}) and hydrogen (H^+) ions, significantly influences soil properties, affecting both land use and soil depth. Adu (1992) report that Elevated exchangeable acidity can hinder plant growth by increasing soil acidity, which in turn reduces the availability of essential nutrients and can lead to aluminum toxicity (Abdulkadir et al 2015).

Table 2 Effect of land use and depth on chemical properties

treatment	EC dS/m	OC g kg^{-1}	N g kg^{-1}	P mg kg^{-1}	C/N ratio	EA
Land use						
Acacia	0.11^{b}	5.6389^{a}	0.5389^{a}	5.7833^{a}	11.012^{a}	0.5489^{a}
Native	0.09^{b}	4.9111^{a}	0.5167^{a}	5.8989^{a}	10.559^{a}	0.5872^{a}
Arable	2.31^{a}	3.0389^{b}	0.4833^{a}	5.0711^{ab}	6.198^{b}	0.4428^{a}
Bare	0.13^{b}	0.9556^{c}	0.4722^{a}	4.2211^{b}	1.905^{c}	0.5333^{a}
Significance level	*	**	Ns	**	**	Ns
SE	0.35	0.4298	0.0278	0.4893	0.9550	0.1026
depth						
0-20	0.72^{a}	3.8408^{a}	0.5083^{a}	5.3396a	7.8495a	0.4600^{a}
20-40	0.63^{a}	3.3200^{a}	0.4958a	5.2763a	6.7693a	0.4908^{a}
40-60	0.64^{a}	3.7475^{a}	0.5042^{a}	5.1150^{a}	7.6372^{a}	0.6333^{a}
Significance level	Ns	Ns	Ns	Ns	Ns	Ns
SE	0.30	0.3723	0.0241	0.4237	0.8271	0.0888
Land use *depth	Sd	Sd	Ns	Ns	Ns	Ns

EC=electric conductivity, OC=organic carbon, N= nitrogen, P= phosphorous, C//N= carbon nitrogen ratio EA= exchangeable acidity

Exchangeable cations:

Calcium had means of 2.7400 cmol kg^{-1}, 2.5506, 2.0139 and 3.9044 cmolkg^{-1} for acacia, native arable and bare land respectively and 2.7125 cmolkg^{-1}, 2.6983 cmolkg^{-1} and 2.9958 cmolkg^{-1} for 0-20cm, 20-40cm and 40-60cm respectively. Magnesium content significantly varied among depth, means of 0.7650 cmolkg^{-1}, 0.8008 cmolkg^{-1} and 0.7347 cmolkg^{-1} for 0-20cm, 20-40cm and 40-60cm respectively land use had means of 0.6150 cmolkg^{-1}, 0.6517 cmolkg^{-1}, 1.0046 cmolkg ^{1}, and 0.7961 cmolkg^{-1} for acacia, native arable and bare land respectively (Table 3). Calcium was higher in 40-60cm, probably due to leaching, colluviation and eluviation-illuviation processes from upper surface and in sub surface soils. Calcium was statistically similar in interaction between location and depth. Calcium accumulated at the subsurface horizons may be accessible to tree species (Mokwunye, 1978). Gong *et al.* (2005) reported that depletion of organic carbon as a result of intensive cultivation reduced EC of soils under arable land. In terms of plant nutrition, magnesium may not be a constraint in the study soils, but its accumulation in soil may have negative impact on soil structure and cause lower water intake rates that may affect chemical and biological properties of soil (Odunze, 2006). Potassium (K) varied in response to different land use types, and slope aspects. Potassium had means of 0.2633 cmolkg^{-1}, 0.2706 cmolkg^{-1}, 0.3306 cmolkg^{-1}, and 0.2483 cmolkg^{-1} for acacia, native arable and bare land respectively (Table 3). K means of 0-20 cm was 0.2729 cmolkg^{-1}, 20-40cm with 0.2446 cmolkg^{-1} and 40-60cm has 0.3171 cmolkg^{-1} respectively (Table 3). Exchangeable K variations were not consistent in all land use types and depth; this may be due to the variations in intensity of weathering; intensive cultivations and use of acid forming inorganic fertilizers that affect distribution of K in soil systems to enhance its depletion (Saikh *et al.*, 1998) According to FAO (2006) classification range (critical level range), <0.2 is very low, 0.2- 0.3 is low and >1.2 is very high. Exchangeable K of soils of the study area was in the range of low to very high (Table 3). Data on exchangeable cations (Table 3) shows that in all soils, calcium was the dominating cation on exchange complex, followed by magnesium, sodium and potassium and occurred in the order of calcium>magnesium>sodium>potassium.

Cation exchange capacity (CEC):

Acacia lands recorded CEC value of 5.1194 cmol kg^{-1} while native has 5.2794 which is higher compared to arable with 5.0217 cmol kg^{-1}, with bare land record slightly higher with 5.8472 cmolkg^{-1} while 0—20cm has 5.1496, while 20-40cm has 5.2079 were CEC increase with depth of 5.5933 in 40-60cm respectively. Cation exchange capacity (CEC) of soil is a very important indicator of soil fertility or at least of potential soil fertility, nutrient availability and could indicate the organic matter content of soil. There was variation in CEC of soils under the four land use types (Table 3). Cation exchange capacity (CEC) of the study area was affected by land use. Woldeamlak and Stroosnijder (2003) reported higher CEC value in soils under natural forest than soils under cultivation. Bhaskar *et al.* (2005) reported lower CEC values obtained in cultivated land and could be partly attributed to the nature of soils and low organic matter content of the soils. Adu (1992) indicated that exchangeable bases are low because of incomplete weathering of primary minerals under prevailing tropical environments, low activity clays and leaching implying; more basic cations could be made available after further weathering of parent materials

base saturation

Base saturation is a critical soil property that influences soil fertility, structure, and land use practices. It represents the percentage of the soil's cation exchange capacity (CEC) occupied by base cations (e.g., calcium, magnesium, potassium, and sodium) relative to acidic cations (e.g., hydrogen and aluminum). Acacia lands recorded percent base saturations value of 72.465% while native has 67.314% which is higher compared to arable with 66.837%, with bare land record slightly higher with 87.052% respectively. High base saturation (>50%) typically indicates fertile soils with a balanced supply of essential nutrients, favoring agricultural uses such as crop cultivation and pasture. Low base saturation (<50%) suggests acidic soils, which may require lime amendments to improve pH and nutrient availability for crops. The percent base saturations of soil in study area recorded the lowest (71.960%) in 40-60cm, the highest ((74.474%) in 20-40cm of subsurface horizon, with (73.818%) in 0-20cm (Table 3). High base saturation in the study area indicates slower weathering and leaching, which can preserve deeper soil profiles with higher nutrient reserves (Odunze 2015). Odunze 2015). reported PBS increased with the depth of soil in study watershed due to its inverse relation with CEC of soil as CEC of soil had strong relation with soil organic matter

Table 3 Effect of land use and depth on chemical properties

treatment	Ca cmolkg^{-1}	Mg cmolkg^{-1}	K cmolkg^{-1}	Na cmolkg^{-1}	BS%	TEB cmolkg^{-1}	CEC cmolkg^{-1}
Land use							
Acacia	2.7400^{b}	0.6150^{a}	0.2633^{a}	0.1217^{a}	72.465^{b}	3.7400^{b}	5.1194^{b}
Native	2.5506^{b}	0.6517^{a}	0.2706^{a}	0.1333^{a}	67.314^{b}	3.6061^{b}	5.2794^{ab}
Arable	2.0139^{b}	1.0046^{a}	0.3306^{a}	0.1611^{a}	66.837^{b}	3.5102^{b}	5.0217^{b}
Bare	3.9044^{a}	0.7961^{a}	0.2483^{a}	0.1274^{a}	87.052^{a}	5.0763^{a}	5.8472^{a}
	**	NS	NS	NS	**	**	NS
SE	0.2709	0.1388	0.0370	0.0370	4.2420	0.3173	0.2285
Depth							
0-20	2.7125^{a}	0.7650^{a}	0.2729^{a}	0.1296^{a}	73.818^{a}	3.8800^{a}	5.1496^{a}
20-40	2.6983^{a}	0.8008^{a}	0.2446^{a}	0.1680^{a}	74.474^{a}	3.9118^{a}	5.2079^{a}
40-60	2.9958^{a}	0.7347^{a}	0.3171^{a}	0.1100^{a}	71.960^{a}	4.1577^{a}	5.5933^{a}
	NS	NS	NS	NS	NS	NS	NS
SE	0.2346	0.1202	0.0320	0.0320	3.6737	0.2748	0.1979
L u *depth	NS	NS	NS	NS	NS	NS	NS

Ca calcium, Mg magnesium, K=potassium, TEB=total exchangeable base, BS= base saturation, CEC =cation exchange capacity

Bulk density

The highest BD was under bare land (1.54 Mg m^{-3}) and arable land (1.43 Mg m^{-3}) fallow by native (1.37 Mg m^{-3}) then acacia (1.21 Mg m^{-3}) The mean value for depths 0-20 cm (1.34 Mg m^{-3}) followed by 20-40cm (1.43 Mg m^{-3}) then 40-60 cm, (1.39 Mg m^{-3}), were observed respectively, results of soil analyses on bulk density (BD) of different land use and depth are presented in Table 4. High bulk density under bare lands was attributed to trampling effects, continuous cultivation in arable land and soil surface sealing/ crusting. Odunze (2012) observed that bulk density rapidly increased with depth in the surface, but remained uniform at depths >20 cm and bulk densities tend to increase with depth primarily due to lack of organic matter and aggregation. Islam and Weil (2000) observed that native vegetation had lower bulk density than arable land attributed it to restricted movement of machine at the forested land compared to continuous cultivation of the cultivated land. Forest litter and roots" decompose over time to improve quality of surface soils and reduce bulk density

Particle densities

Acacia land had means of 2.58 Mg m^{-3} while native vegetation land had 2.50 Mg m^{-3} fallow by arable and bare land with 2.44 Mg m^{-3}, and 2.53 Mg m^{-3} respectively. Particle density of 2.49 Mg m-3, 2.53 Mg m-3 and 2.52 Mg m-3 were recorded for 0-20, 20-40cm and 40-60cm respectively (Table 4). Particle density in land use and depth was not significantly differ at>0.05. The finer soil particles were selectively removed by erosion, thereby increasing proportion of coarser particles and leaving more sand particles (Ayoubi *et al*., 2011). Soils with higher proportion of sand particles have higher particle density (Brady and Weil, 2002). Particle density increased with depth and could be due to reduction of soil organic matter (OM) with increasing depth.

Total Porosity

Acacia has the values of total porosities of 50.48 %, native vegetation had 45.70% and arable has the mean of 50.63% then bare land with 46.99%. the depth the mean values of 48.16%, 48.24% and 48.16 % were obtained for 0-20, 20-40 and 40-60cm respectively (Table 4) were statistically similar. Porosity decreased with depth, which could be due to reduction of soil organic matter (OM) with decreasing slope steepness or length. The lowest total porosity recorded in moderately steep middle slope cultivated was attributed to surface wash by erosion and exposure of sub soil layers, high bulk density, low clay content and low organic matter content (Table 4) at this geomorphic position. According to FAO (2006), rating of total porosity values in all slope gradients were high (greater than 40 %), indicating that the study area soils were mostly within the 40 to 50 percent rating forgood agricultural soils (FAO, 2006).

Hydraulic conductivity (Ks)

Table 9 shows value of saturated hydraulic conductivity (Ks) under different land use types. Acacia land Ks was 2.98 cm h^{-1} while native vegetation has 2.83 cm h^{-1}, arable has 2.81 cm h^{-1} and bare land has the mean of 3.95 cm h^{-1} similarly 0-20cm, 20-40cm and 40-60cm had means of 2.85 cm h^{-1}, 3.71 cm $^{h-1}$ and 2.88 cm h^{-1} respectively. (Table 4). This might be due to increased bulk density with depth as observed by Ohu *et al.* (1989). Also increase in clay content with depth would cause clay particles to clog conducting pores and decrease saturated hydraulic conductivity (Okai, 2001). The value of Ks was extremely low at lower depth, perhaps due to nature of clay and soil compaction. Comparison of the four land uses showed that hydraulic conductivity at top soils of acacia lands was significantly higher than in arable soils.

This might be due to difference in clay, organic matter content, surface sealing/crusting and soil compaction at cultivated sites. Hydraulic conductivity was similar in interaction between location and depth. Overall, these findings agree with results reported by Jabro *et al*. (2009) that greater Ks values correspond with lower soil bulk density values at the subsurface depth

Dry Means Weight Diameter (DMWD)

Acacia had mean dry aggregate fractions of 1.21 mm; while native land had 1.21mm arable land has 1.21 mm and bare land has 1.2 mm. depth of 1.19 mm, 1.22mm, 1.21mm for 0-20cm, 20-40cm and 40-60cm respectively. (Table 4). This implies a negative impact of tillage on aggregate size distribution when compared with values in acacia and native vegetation land use. Dry aggregate size distribution is one of the major physical characteristics of soil that strongly affects soil quality, fertility and its resistance to erosion and degradation and is also considered an indicator of soil structure (Odunze *et al.,* 2013). The high proportion of large macro-aggregates and macro-aggregates fractions in barema acacia plantations might be attributed to addition of litter materials and the symmetrical nature of plant root with lateral roots positively aiding aggregate stability through additional cohesion of soil particles (Odunze, 2012). Exudates from tree roots and microbial excretions into the soil might have also aided aggregation process by acting as cementing agents (Haynes and Francis, 1993). This result supports earlier findings of Ogunwole and Ogunleye (2004), who reported 11 % increased turnover of macroaggregates under *Jatropha curcas* L (JCL) plantation on a degraded Indian Entisol over native vegetation.

The possible reason for this high value may be associated with high amounts of divalent cations which accompany applications of manure and inorganic fertilizer. The implication of this is that land with highest mean value of dry MWD will have better stable aggregates that can withstand wind erosion than other treatments, while those with low mean values may be most vulnerable to wind erosion due to low dry stable aggregates (Ogunwole and Ogunleye, 2004). Increasing intensity of cultivation can reduce carbon

Wet Mean Weight Diameter (WMWD)

Acacia land recorded 1.1867 mm; while native vegetation has 1.1883 which was lower than arable land with 1.2028mm.and bare land with 1.2072 Similarly, 0-20cm record 1.1950mm and 20-40cm has 1.1996mm with 40-60cm get 1.1942mm respectively. (Table 4). The mean water stable aggregates were similar for both land uses. The wet MWD recorded in the land use may be associated with degradation of large macro-aggregate fractions in the dry soil when immersed in water (Unger, 1997), a situation consistent with natural wetting by intense rain. Perhaps, soil amendments used (Farmyard manure and inorganic fertilizer) by farmers may account for this soil improvement index. Denef *et al.* (2001) reported that stability of wet aggregates can be related to surface seal development and field infiltration, as water-stable cohesion among particles may lead to restriction of water entry and formation of surface seals. Generally, additions of organic material in the form of either farmyard manure or through the decomposition of plant residue over long periods of time play a significant role in the stability of aggregates in water or wind. This improves the soils capability for withstanding water erosion (Ogunwole and Ogunleye, 2004).

Table 4 Effect of land use and depth on physical properties

treatment	Bd Mg m^{-3}	pd Mg m^{-3}	Porosity%	Ksat cm h^{-1}	DAG (mm)	WAG (mm)
Land use						
Acacia	1.2100^{b}	2.5889^{a}	50.481^{a}	2.9894^{a}	1.2161^{a}	1.1867^{a}
Native	1.3706^{ab}	2.5067^{ab}	45.704^{a}	2.8389^{a}	1.2117^{a}	1.1883^{a}
Arable	1.4333^{a}	2.4456^{b}	50.639^{a}	2.8111^{a}	1.2128^{a}	1.2028^{a}
Bare	1.5456^{a}	2.5378^{ab}	46.997^{a}	3.9539^{a}	1.2094^{a}	1.2072^{a}
significant level	Ns	Ns	Ns	Ns	Ns	Ns
SE	0.0672	0.0391	2.8051	0.5553	0.0137	0.0116
depth						
0-20	1.3425^{a}	2.4983^{a}	48.966^{a}	2.8513^{a}	1.1988^{a}	1.1950^{a}
20-40	1.4304^{a}	2.5350^{a}	48.240^{a}	3.7133^{a}	1.2250^{a}	1.1996^{a}
40-60	1.3967^{a}	2.5258^{a}	48.160^{a}	2.8804^{a}	1.2138^{a}	1.1942^{a}
SE	0.0582	0.0338	2.4293	0.4809	0.0118	0.0101
Land use *depth	ns	ns	ns	ns	ns	ns

DAG=dry aggregate, WAG= water aggregate, BD=bulk density, PD = particle density, Sat= hydraulic conductivity

Criteria for Soil Quality Monitoring and Evaluation in barema farm reserve.

Soil quality monitoring and evaluation involve assessing soil health over time to determine its ability to function effectively within an ecosystem. This includes supporting plant growth, maintaining environmental quality, and sustaining biological productivity. The criteria for monitoring and evaluating soil quality typically encompass the following: Soil quality monitoring and evaluation involve assessing soil health over time to determine its ability to function effectively within an ecosystem. This includes supporting plant growth, maintaining environmental quality, and sustaining biological productivity. The criteria for monitoring and evaluating soil quality typically encompass the following. Soil Physical Properties such as Texture, Proportions of sand, silt, and clay, affecting water retention and drainage. Structure Soil aggregation and porosity influence aeration, root penetration, and water infiltration. Bulk Density, indicates compaction, which affects root growth and water movement. Hydraulic conductivity Measures the soil's ability to retain water for plant use. Soil Chemical Properties such as pH to Determines the soil's acidity or alkalinity, which impacts nutrient availability. Organic Matter Content to Affects fertility, structure, and water-holding capacity. Nutrient Levels: Includes macronutrients (N, P, K) and micronutrients necessary for plant growth. Cation Exchange Capacity (CEC): Reflects the soil's ability to hold and exchange nutrients. Salinity: Measured by electrical conductivity, high levels can inhibit plant growth. To monitor soil quality, treatment means for bulk density, mean weight diameter, pH in H2O and $CaCl_2$, organic carbon, total nitrogen, available phosphorus, cation exchange capacity was matched as shown in the (Table 5). Bulk density shows that acacia soil had the least bulk density 1.2100 Mg m^{-3} fallow by native vegetation with mean of 1.3706 Mg m^{-3} while arable land had1.4333 Mg m^{-3} with bare land had the highest bulk density 1.5456 Mg m^{-3} (Table 5). Table 4 shows that mean weight diameter dries for acacia land (1.2161mm) and native vegetation had(1.2117mm) arable land (1.2128mm) and bare land had (1.2094mm). The pH in H2O and CaCl2 shows that pH decreased slightly under cultivation and increased under forest. Both pH in H2O and CaCl2 followed the same trend. Table 3 shows that there was increase in organic carbon contents under acacia (5.6389 g kg^{-1}) decrease in native with 4.9111 g kg^{-1}while arable and bare land show decrease in organic carbon content (3.0389 g kg^{-1}, 0.9556 g kg-1) respectively Also, Table 5 shows that a total N content of (0.5389 g kg^{-1}) was observed in the acacia land, while native land with 0.5167 g kg^{-1}. While arable land had 0.4833 and bare land had 0.4722 respectively. Table 5 shows that native vegetation land had the highest content of available P (5.8989 mg kg^{-1}), fallow by acacia 5.7833 mg kg^{-1} arable and bare land had the least (5.0711 mg kg^{-1}, and 4.2211 mg kg^{-1}) respectively. and this could be attributed to crop uptake of phosphorus since it has been proven that legumes use up phosphorus more and the presence of legume facilitates the utilization of soil phosphorus by crops in the low P soil of Northern Guinea Savanna of Nigeria Thomas (2000).Cation Exchange Capacity (CEC) decreased slightly under acacia (5.1194 cmol kg^{-1}), and increased slightly with native 5.2794 cmol kg^{-1} with lease in arable land 5.0217 cmol kg^{-1} highest observed in bare land 5.8472 cmol kg^{-1} in CEC would imply that soil health/quality over the years had been positively impacted upon by the management practices (McRae and Mehuys, 1988; Carlson and Huss-Danell, 2003). Table 5 shows that 0-20cm had the least bulk density (1.3425 Mg m^{-3}) while 20-40cm had the highest bulk density 1.4304 (Mg m^{-3} then 1.3967 (Mg m^{-3}) record in the 40-60cm, it's also shows that there was increase in organic carbon contents under 0-20cm 3.84 g kg^{-1} fallowed by 20-40cm with 3.3200 g kg^{-1} then 40-60cm3.7475 g kg^{-1}. Total N content of 0.5083 g kg^{-1} was observed at 0-20cm, 0.4958 g kg^{-1} and 0.5042 g kg^{-1} at 20-40cm and 40-60cm respectively. Table 5 shows that 0-20cm had the highest content of available P among the other depth, this could be attributed to crop uptake of phosphorus and the presence of legume facilitates the utilization of soil phosphorus by crops in the low P soil of Northern Guinea Savanna of Nigeria (Kalm *et al*. 2002). It shows that CEC decreased slightly under 40-60cm 5.1496 cmol kg^{-1}, 5.2079 cmol kg^{-1} at 20-40cm and increased under 0-20cm 5.5933 cmol kg^{-1}. Table 7 shows that upper surface 0-20cm increased in dry mean weight diameter with 1.1988mm while 20-40cm had 1.2250 mm. 40-60cm show least in wet mean diameter (1.1988 mm) and 20-40cm (1.2138mm), while 40-60cm shows slightly decrease with (1.2138 mm) Table 5. It shows that pH in water decreased slightly under 20-40cm and increased under 40-6-cm. Decrease in soil pH however, was not sufficient to hamper crop growth. Both pH in H2O and $CaCl_2$ did not followed the same trend. Management practices which were superior by improving soil quality were ascertained from results and a summary of the threshold limits using soils that were superior as a baseline is presented in Tables 6 and 7.

Table 5: Threshold limits for soil quality assessment in Barema Alfisols Using Minimum Data Set for land use

Soil parameter	Acacia vegetation	Native vegetation	Arable land	Bare land
Bulk density (Mg m^{-3})	1.2100	1.3706	1.4333	1.5456
Organic carbon (g kg^{-1})	5.6389	4.9111	3.0389	0.9556
Total nitrogen (g kg^{-1})	0.5389	0.5167	0.4833	0.4722
A. phosphorus (mg kg^{-1})	5.7833	5.8989	5.0711	4.2211
CEC (cmol kg^{-1})	5.1194	5.2794	5.0217	5.8472
Dry mean weight	1.2161	1.2117	1.2128	1.2094
Wet mean weight	1.1867	1.1883	1.2028	1.2072
pH (H_2O (1:2.5)	6.1611	6.2067	6.1856	6.2633
pH ($CaCl_2$) (0.01M)	6.0417	6.1322	6.0572	5.9583

Table 6: Threshold limits for soil quality assessment in Barema Alfisols. using minimum data set for depth

Properties	0-20cm	20-40cm	40-60cm
Bulk density (Mg m^{-3})	1.3425	1.4304	1.3967
Organic carbon (g kg^{-1})	3.8408	3.3200[a]	3.7475
Total nitrogen (g kg^{-1})	0.5083	0.4958	0.5042
Available phosphorus (mg kg^{-1})	5.3396a	5.2763	5.1150
CEC (cmol kg^{-1})	5.1496	5.2079	5.5933[a]
Dry mean weight	1.1988[a]	1.2250[a]	1.2138
Wet mean weight	1.1950[a]	1.1996	1.1942
pH (H_2O (1:2.5)	6.2200	6.1738	6.2188
pH ($CaCl_2$) (0.01M)	6.0988	5.9988	6.0446

Table 7: Soil Quality Monitoring and Evaluation in barema farm, Nigeria

Soil of Barema farm plantation

Soil parameter	High	medium	low
Bulk density (Mg m^{-3})	≥ 1 4	1.2– 1.4	< 1.2
Organic carbon (g kg^{-1})	> 15	10 – 15	< 10
Total nitrogen (g kg^{-1})	0.3	0.2-0.3	<0.2
Available phosphorus (mg kg^{-1})	≥ 4 0	2.5 – 4.0	< 2.5
CEC (cmol kg^{-1})	>8.0	7.0 – 8.0	< 7.0
Dry mean weight	≥1.5	1.3 – 1.5	< 1.3
Wet mean weight	≥1 5	1.3 – 1.5	< 1.3
pH (H_2O (1:2.5)	>5.5	4.8 – 5.5	< 4.8
pH ($CaCl_2$) (0.01M)	>4.5	4.0 – 4.5	< 4.0

Note: > is greater than, < less than, > greater than or equal to, < less than or equal to

Soil quality evaluation

Soil of the land uses and depth were cumulatively rated for quality base on the SMAF protocol and the results are shown in Table 8. Each of the indicator values was divided by a common denominator (highest possible measurement for indicator in the land uses and depth plus 10 % of it) before being subtracted from 1 (in the case of parameters for which less is better). There is the tendency for indicator with lower denominator to have higher value than indicator with higher denominators. These explain variability in the individual scores for different indicators. When cumulatively put together however, acacia vegetation soil had the highest score index followed by native vegetation soil, then arable land with least in bare land, for the depth, 40-60cm is higher than 0-20cm with least been 20-40cm.when cumulatively put together, the variation order of soil is (acacia > native > 40-60cmdepth>0-20cm>20-40cm>arable >bare land) indicate the direction of good quality of soil. Soil quality was assessed using a score scale of 1 to 6; where 1 is rated best and 6 rated worst. Thus; acacia with highest total score was rated best, while bare land with lowest total score rated worst. Acacia scored best and enhance soil quality conditions (optimum soil organic carbon, total nitrogen, available phosphorus, potassium, EC, and bulk density), while bare land was rated worst (low organic carbon, low k, moderate phosphorus, moderate nitrogen, low bulk density and electrical conductivity (Table 8)

Table 8: Combining indicators scores into the index (SMAF protocol)

Functions	Indicators	Acacia	Native	Arable	Bare	0-20cm	20-40cm	40-60cm
Ease of tillage	Bulk density	0.012	0.013	0.014	0.015	0.013	0.014	0.013
Bio activities	Organic matter	0.056	0.049	0.030	0.009	0.038	0.033	0.037
Support plant growth	Total N	.0.005	0.005	0.004	0.004	0.005	0.004	0.005
Plant growth	Available p	0.057	0.058	0.050	0.042	0.053	0.052	0.051
Plant nutrient	CEC	0.051	0.052	0.050	0.058	0.051	0.052	0.055
R air erosion	Dry mean weight	0.012	0.012	0.012	0.012	0.011	0.012	0.012
R water erosion	Wet mean weight	0.011	0.011	0.012	0.012	0.011	0.011	0.011
Salinity	pH(H_2O(1:2.5)	0.061	0.062	0.061	0.062	0.062	0.061	0.062
Salinity	pH($CaCl_2$)(0.01M)	0.060	0.061	0.060	0.059	0.060	0.059	0.060
Total (Index)		0.325	0.323	0.293	0.273	0.304	0.298	0.306

Combining the indicators scores into the index

This involves developing scoring function for each individual soil quality indicator and transforming the score into dimensionless values thus ranking them into a specified numerical value (Anikwe 2006). Each individual indicator is combined with several other indicators in the minimum data set to form a set of soil quality indicator to evaluate a soil for specified applied practical purpose (Anikwe 2006). It is important to note that for each indicator, a scoring function and realistic baseline and threshold value. The values for the scoring function are either neither specific for a kind of land use for specific kind of sol quality evaluation for specific management practice (Sani et al, 2023: Anikwe 2006). Therefore, soil quality rating is calculated by summation of weight scores for each of soil function

Table 9: Ranking of soil quality under different land use and depth

Land use and depth	Total score	Percentage	Ranking
Acacia	0.325	32.5	1
Native vegetation	0.323	32.3	2
40-60cm	0.306	30.6	3
0-20cm	0.304	30.4	4
20-40 cm	0.298	29.8	5
Arable	0.293	29.3	6
Bare land	0.273	27.3	7

A score scale of 1 to 6 was used in the assessment of parameters; where 1 is best and 6 is the worst condition.

CONCLUSION

Despite the benefit of turnover increase in soil organic matter through cattle droppings during grazing cycle as perceived by peasant farmers in Northern Nigeria and elsewhere; it's might result to soil compaction of the surface layer more devastating than conventional arable cultivation as showed by this study Use of disc plough in conventional tillage for arable crop production could result in low bulk density in the upper 20 cm, while the compacted layer might be found beneath this layer. Therefore, subsequent researches investigating the effect of tillage on soil compaction are advised to go beyond the upper 60 cm soil layer acacia showed some possibilities of enriching nitrogen and stability of Nigerian Savanna Alfisol soil to wind erosion better than native vegetation and arable cultivation. But, still a long-term study on the influence of acacia on soil quality is needed in order to understand if such possibilities are sustainable

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