

## Original Research Article

Effect of land use on soil quality in afaka forest northern guinea savannah of  
Nigeria

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### ABSTRACT

*Land use changes from forest into cultivated ecosystems result in negative impact on soil structure and quality. The purpose of this study was to determine Effect of land use on soil quality in Afaka forest northern guinea savannah of Nigeria. Land use systems, including natural forest and cultivated land were identified. Eighteen (18) composite disturbed and undisturbed samples were collected from depth of 0-5 and 5-10cm for analysis of pertinent soil properties in the laboratory using rigid grid procedure. Most physical and chemical properties show relative variations in response to land use types and geomorphic positions. Results indicated that the soils had high degree of weathering potentials, low to moderate bulk density at 0-5cm depth values range between 1.42 to 1.49 Mg m<sup>-3</sup> in forest and cultivated land, bulk density at 5-10cm depths had values ranging between 1.34 and 1.46 1.Mg m<sup>-3</sup> for forest and cultivated land respectively. The highest soil moisture contents at 0-5cm depth were 4.20, 2.63 cm<sup>3</sup>/cm<sup>3</sup>, while at 5-10cm depths values were 4.32 and 2.13 cm<sup>3</sup>/cm<sup>3</sup> recorded under forest and cultivation land use. The pH (H<sub>2</sub>O) ranged from 6.9 to 7.16 in the land uses. The electrical conductivity in the land uses was 0.13 dS/m and 0.12 dS/m was obtained for forest and cultivation land respectively, The CEC of 8.60 cmol kg<sup>-1</sup> and 8.54 cmol kg<sup>-1</sup> was recorded on forest and cultivated land uses, the total nitrogen content of 1.21 g kg<sup>-1</sup> and 1.11 g kg<sup>-1</sup> for forest and cultivation land uses was recorded. The highest available phosphorus of 8.78 mg kg<sup>-1</sup> and 5.47 mg kg<sup>-1</sup> was recorded under cultivated and forest land uses. Results indicate that soil fertility parameters were moderate to low in soils of cultivated land and all slope positions, suggesting that soil fertility management is required in order to make agriculture sustainable on Afaka area.*

## Introduction

Land use-induced changes in nutrient availability may influence secondary succession and biomass production (Foster *et al.*, 2003) and reduce soil organic carbon (SOC); which plays a crucial role in sustaining soil quality, crop production and environmental quality (Doran and Parkin, 1994). Such changes directly affect soil physical, chemical and biological properties; such as soil water retention and availability, nutrient cycling, gas flux, plant root growth and soil conservation (Gregorich *et al.*, 1994). Maintenance of SOC is especially important due to its effect on soil nutrient status and structural stability. Afaka study area is facing the problem of deforestation, over grazing, poor soil management and severe erosion. Combating and minimizing on-going soil degradation and enhance land productivity through sustainable use of soil resources requires understanding the soil physico-chemical characteristics under different land use systems. However, very little information is available about the study area. Therefore the present study was undertaken to evaluate effect of different land use systems and slopes on selected physical and chemical properties of different land use system in Alfisols of Afaka area

Soil quality is defined as the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Brady and Weil, 1999). Thus, soil quality assessment reflects biological, chemical and physical properties, processes and their interactions within each resource unit (Karlen *et al.*, 2001). Over the last decade, soil quality has been one of the topics of great interest in Soil Science, so much so that a database such as the Soil Science CAB Database (CAB International Publishing) supplies more than 1500 publications that use the term 'soil quality' as a key word. Interests have been focused on defining the concept of soil quality and searching for reliable ways for assessing the quality of soils. In recent years, defining

soil quality has put into consideration the key involvement of the soil in crop production, water and atmospheric purification and thus emphasis is laid on the role of the soil both for production and for environmental quality improvement. This has led to a profusion of definitions of soil quality, but that of Karlen *et al.* (1997) which states that “soil quality is the capacity of a specific kind of soil to function, within forest or cultivated land that sustain plant and animal productivity, maintaining water and air quality, support human health and habitation”, is widely accepted. Some important soil functions include; water flow and retention, solute transport and retention, physical stability and support, retention and cycling of nutrients, buffering and filtering of potentially toxic materials and maintenance of biodiversity and habitat (Andrews *et al.*, 2004).

## MATERIALS AND METHOD

### Site description

The study area is Afaka forest reserve, established in 1946, situated some 24 kilometers north – west of Kaduna and is roughly bisected by Kaduna-Tegina road (Figure 1). The area lies between Latitude 10<sup>0</sup> 37', N and Longitude 07<sup>0</sup> 15' E, ~~near milestone 132 south of the road and currently covers an area of~~ 129 ha (FDRF 1964). The altitude is approximately 1950 ft (585 m) above ~~mean~~ sea level. The area is ~~virtually~~ flat with ~~a~~ very gentle slopes ~~running towards~~ to the south. Drainage is generally imperfect due to the occurrence of compacted or indurate layers in much subsoil and not to the topography (FDRF, 1964). The mean annual rainfall is ~~between~~ 1011 mm ~~to~~ 161 mm; which is received mainly ~~between from~~ May to September, with peak rainfall in August (Oluwasemire and Alabi, 2004 ~~check reference may be given as number in text~~).

**Comment [A2]:** Introduction  
Sir please revise this introduction . finely drafted the review of literature but not highlighted why present study was undertaken in afaka forest northern guinea savannah of Nigeria referring to soil quality. It is missing . What is the hypothesis of your study with well defined objectives.

**Comment [A3]:** Check reference quote , may be number

**Comment [A4]:** Please refer to imperfect drainage

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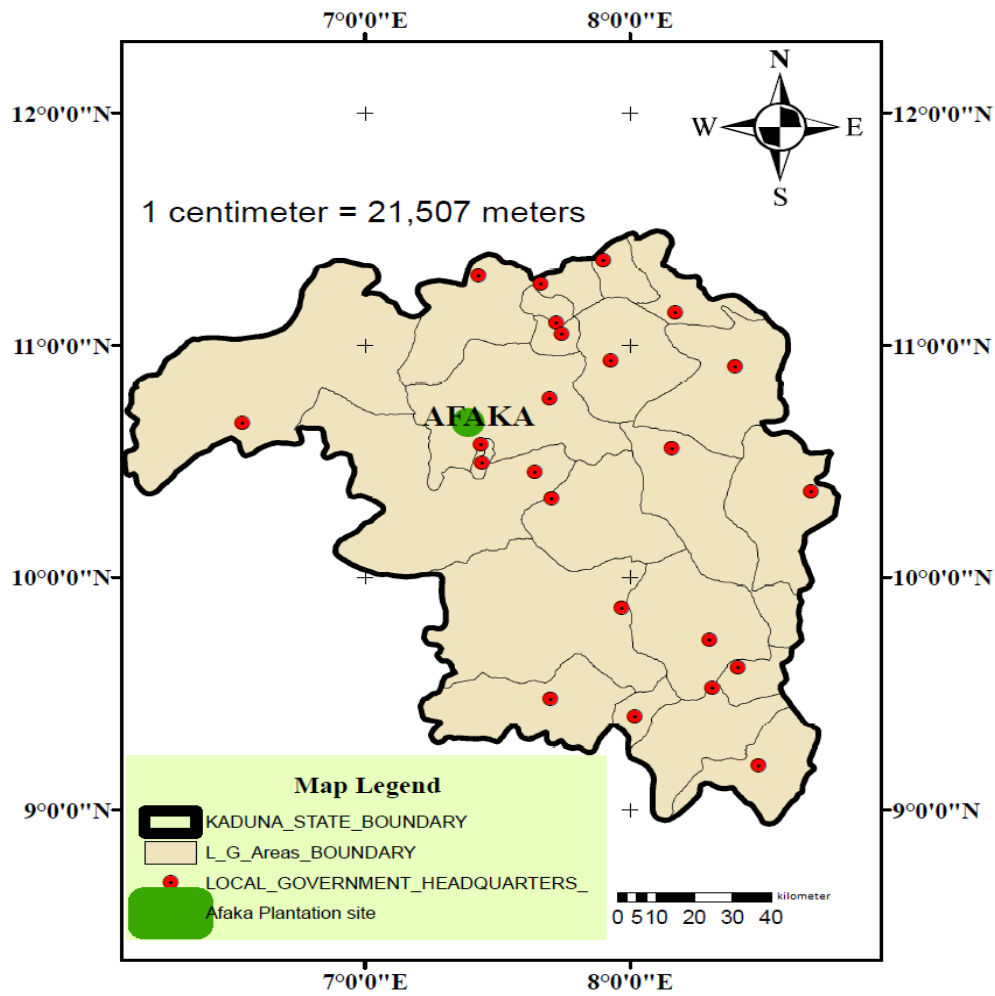


Figure 1: Map of Kaduna State showing Afaka forest reserve

**Comment [A5]:** Index map showing Nigeria then atate or province and then study site

**Soil Ssampling plan:** Soils on geomorphic positions were sampled on a rigid grid detailed survey plan.

**Comment [A6]:** When it is grid survey, how geomorphic positions matter

Soil samples from depth of 0- 5 cm (top soil ) and 5 -10 cm (lower layer ) were collected at auger points determined along traverses from cultivated land and in adjacent forest, in each delineated geomorphic position of the study area. The sample area covered 1 km by 1 km dimension. This involved use of traverse lines perpendicular to the baseline. Natural features such as road were chosen as baseline (Figure 2). In all, ten traverse lines were proposed, such that augering was done at 100 m interval along each transverse. The different locations were selected based on identification of typical Afaka forest vegetation, identified typic-toposequence and crop cultivated sites.

**Comment [A7]:** Not justified, revise this sentence

UNDER PEER REVIEW

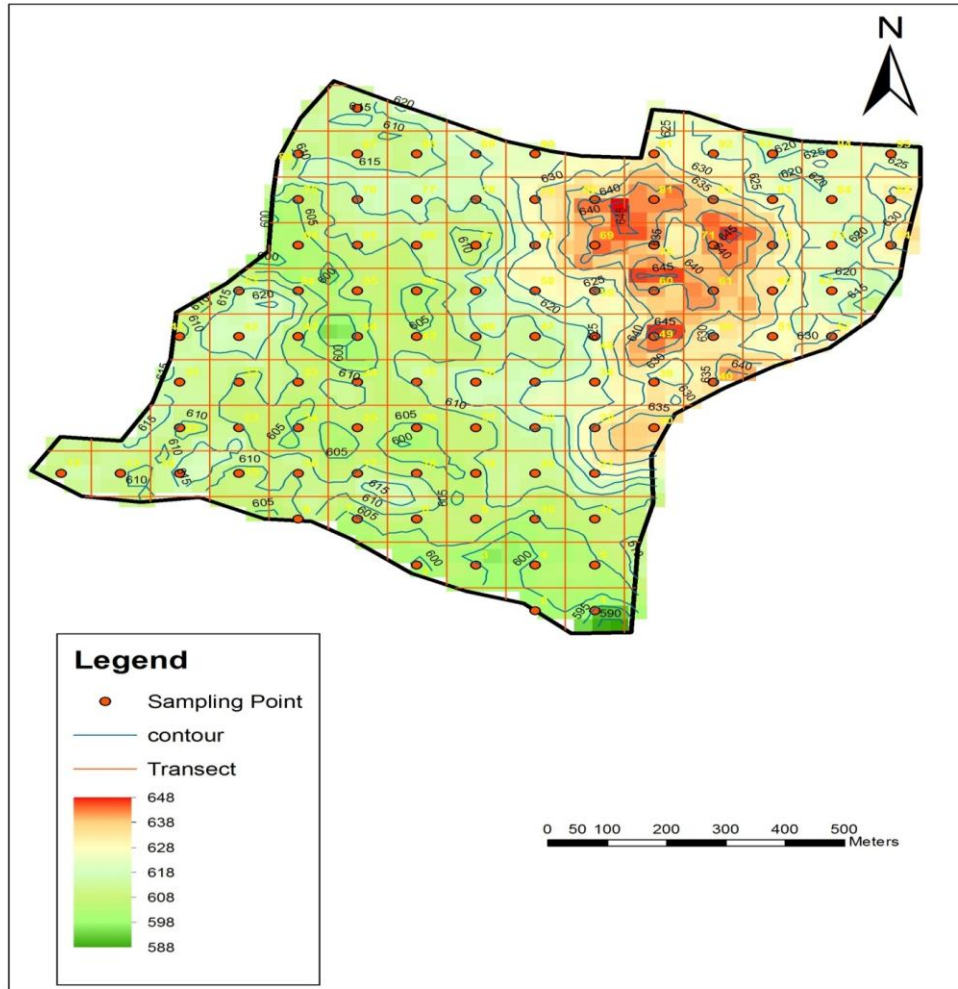


Fig 2: Map Showing Soil Geomorphic Positions and Sampling point in Afaka Forest Reserve

### Determination of bulk density

Six undisturbed soil samples from three geomorphic unit at two land use type was taking, undisturbed soil core samples of 45 mm diameter and 50 mm height from 0-5 and 5-10 cm depths were obtained for the determination of bulk density of each land use system and geomorphic location as described by Blake and Hartge (1986). The samples were oven dried at 105°C for 24 hours after which they were weighed. The weight of empty core samplers was also taken and mass of the soil was determined. Bulk volume was obtained by measuring internal diameter and height of the cylinder, so that volume of the soil was expressed as:

$$V = \pi r^2 h$$

Where

$V$  is volume of the core (cm<sup>3</sup>),  $r$  is the radius (cm),  $h$  is the height of the core and  $\pi$  is 3.142

Bulk density was calculated as:

$$\rho_p = \frac{\text{weight of oven dry soil}}{\text{volume of soil}} \left( \frac{g}{cm^3} \right) \quad \text{Or} \quad \text{Mgm}^{-3}$$

### Determination of soil pH

Soil pH of each soil sample obtained from auger points was determined both in water and 0.01M CaCl<sub>2</sub> solution, using a soil to solution ratio of 1:2.5 (Rhoades, 1982)

### Exchangeable bases (Ca, Mg, K, and Na)

**Comment [A8]:** Why six undisturbed samples in 3 units of two land use types

Exchangeable Bases (Ca, Mg, K and Na): Exchangeable Ca, Mg, K and Na were extracted in ammonium acetate (1N NH<sub>4</sub>OAc) solution using 1:10 soil to solution ratio according to Agbenin (1995). Calcium (Ca) and Magnesium (Mg) were determined by EDTA titration method (Agbenin, 1995). Potassium (K) and Sodium (Na) were determined using flame photometry (Anderson and Ingram, 1993).

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### Cation exchange capacity (CEC)

The cation exchange capacity (CEC) was determined after extracting the soil samples by ammonium acetate (1N NH<sub>4</sub>OAc) at pH 7.0, [give reference , method is incomplete](#)

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### Total Nitrogen

The total nitrogen determination was done using macro kjeldahl method as described by Bremner (1982). This involves mixing of 10 ml distilled water inside a 500 ml kjeldahl flash, 3 g of Kjeldahl catalyst, 15ml of concentrated H<sub>2</sub>SO<sub>4</sub> and soil sample. This was heated and later mixed with 75 ml of 10 M of NaOH and granular Zinc. The digest was distilled and about 50 ml of the distillate was collected ~~which was then~~ titrated with 0.05 M H<sub>2</sub>SO<sub>4</sub> ~~to till~~ pink end point. The nitrogen content was calculated by the formula:

$$N\% = \frac{0.014 \times (\text{Titre value} - \text{Blank titre value}) \times NA \times \text{Vol. of digest} \times 100}{\text{Weight of soil} \times \text{Aliquot taken}}$$

Where NA = Concentration of acid used

$$N \text{ (g/kg)} = N \text{ (%) } \times 10$$

**Available phosphorus** was determined by Bray-1 extraction method (Bray and Kurtz, 1945). [brief description is needed](#)

### Soil quality evaluation



Soil quality evaluation was based on the soil management assessment framework (SMAF) suggested by Andrews *et al.* (2004), scoring functions for 14 potential soil quality indicators (Wienhold *et al.*, 2009). A general guideline has been the use of minimum of five indicators with at least one each for biological, chemical and physical properties or process (Karlen *et al.*, 2011) as suggested by Larson and Pierce (1992); a minimum data set (MDS) was established. The MDS 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 were used as indicators for plant growth support, while organic carbon was indicator for biological activity in the soil and MWD to assess erodibility of the soils. Indicators were divided into three, more is better was applied to N, P, K and organic matter, while less is better which applied to bulk density, optimum is better which applied to pH (Larson and pierce 1994).

**Comment [A9]:** How measure this MWD not explained in methods

**Comment [A10]:** Revise this sentence

### 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 step

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- 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

Table 1 show Soil quality indicators selected for minimum data set and its function

Indicators of soil condition	Relationship to soil condition and function
	physical
Texture	Retention and transport of water and chemical,
Bulk density and infiltration	Potential for leaching ,productivity and erosivity
Water holding capacity	Related to water retention ,transport and erosivity, available water texture and organic matter
	chemical
Soil organic matter	Fertility and stability
pH	Biological and chemical activity threshold
Electrical conductivity	Plant and microbial activity
Extractable N, P, and K	Plant loss available and for N
	biological
Microbial biomass C and N	Microbial catalytic
Potentially mineralization	Soil productivity and N supplying potential
Soil respiration, water content and temperature	Microbial activity

(Larson and Pierce, 1992).

### Transforming indicators score

This involve selecting MDS for assessing a particular management objective, Karlen *et al.*,(2001) explained that this step is required so that biological, chemical and physical indicator measurement with totally different measurement unit can be combined. Andrew and Carol, (2001) emphasized simplicity of design and use by developing a linear scoring techniques that relies on the observed of data to determine the highest possible score for each indicator and non-linear score technique involve the use of curve linear scoring functions with a y-axis ranging from 0 to one and x axis representing a range of site of function

- 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, would electrical conductivity Anikwe (2006)

**Comment [A12]:** Eptimize not needed full details

### Statistical Analysis

Analysis of variance (ANOVA) test was done to determine significant difference among treatments. 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). Correlation analysis was also used to determine level of relationship between soil properties of the slopes and the land uses.

**Comment [A13]:** Why Anova is done /

**Comment [A14]:** Where are treatments

## RESULTS AND DISCUSSION

### Bulk density

The highest BD was under cultivated land at depths 0-5 cm ( $1.49 \text{ Mg m}^{-3}$ ) followed by 5-10 cm ( $1.46 \text{ Mg m}^{-3}$ ), under forestland. The bulk density of surface layer (0-5cm) is  $1.49 \text{ Mg m}^{-3}$  as against the forestland ( $1.46 \text{ Mg m}^{-3}$  at 5-10cm). In contrast, the low BD values at 0-5 cm ( $1.42 \text{ Mg m}^{-3}$ ) and 5-10 cm ( $1.34 \text{ Mg m}^{-3}$ ) were observed under forestland. Results of soil analyses on bulk density (BD) of under different land uses are presented in Table 2. High bulk density under cultivated lands was attributed to trampling effects, continuous cultivation and soil surface sealing/ crusting. Odunze (2012) observed that bulk density rapidly increased with depth in the surface, but remained uniform at depths more than  $\rightarrow$  20 cm and bulk density tends to increase with depth primarily due to lack of organic matter and aggregation. Islam and Weil (2000) observed that Forestland had lower bulk density than cultivated land and attributed it due 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. Evrendilek *et al.* (2004) also reported that conversion of forestland into cultivated land during a 12-year period increased bulk density and decreased total porosity. Perhaps, Forestland had higher organic matter (OM) content; making the soil loose, porous and well-aggregated, that might have reduced soil bulk density. The result also shows that bulk densities decreases with slope. The variation of soil bulk density among slope gradients might be attributed to variation of in disturbance of soil particles by erosion. Suspended finer particles were transported down the slope where they accumulate at the bottom; thus increasing clay and silt content at the bottom slope positions with higher micro porosity and lower bulk density (Midkiff, *et al.*, 1985).

**Comment [A15]:** Recheck the statement , is it not cultivated but the same mentioned for forestland in 3<sup>rd</sup> and 4<sup>th</sup> layer.

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### Available moisture-water content

Available moisture content was determined at two depths (0-5 cm and 5-10 cm). Result shows that forest retained highest moisture content water content of 4.20 cm<sup>3</sup>/cm<sup>3</sup> at 0-5 cm and 4.32 cm<sup>3</sup>/cm<sup>3</sup> at 5-10 cm, while the lowest moisture-water content of 2.82 cm<sup>3</sup>/cm<sup>3</sup> at 0-5 cm and 2.79 cm<sup>3</sup>/cm<sup>3</sup> at 5-10 cm were observed under cultivated land (Table 2). ~~were significantly different (P < 0.05)~~. The interaction result of water retention with slope shows that middle slope ~~forest record~~ soils have water content of high with 4.50 cm<sup>3</sup>/cm<sup>3</sup> ~~followed~~ allow by middle slope cultivated but statistically similar with lower and upper slope forest, but significantly different for upper and lower slope cultivated ~~(Table 2)~~. This confirms that cultivation deteriorates soil structural aggregation and reduces soil water retention capacity (Wakene, 2001). Soil moisture ater retention at ~~content at~~ field capacity (FC) for all land use systems show decrease in trend with depth (Wakene, 2001). Considering land uses on different topographic positions, greater water retention at of forestland was observed in soils of middle slope positions. This difference in moisture-water content was attributed to effect of soil type, position on topography and organic matter content. Total available water was highest in natural forestland (Table 2). Higher clay and organic carbon (OC) provided large surface area required for absorption and retention of water molecules (Materechera and Mkhabela, 2001). Natural forest soils have more available water holding capacity compared to cultivated lands (Ayoubi, 2011).

**Comment [A18]:** Make ststement with the values recorded in soils of study site.

Table 2: Effects of Land Use and Slope on Dry and Wet Mean Weight Diameter, bulk density, and available moisture content.

Bulk density (Mg m <sup>-3</sup> )	5-10cm	AMC 0-5 cm (cm <sup>3</sup> /cm <sup>3</sup> )	5-10 cm (cm <sup>3</sup> /cm <sup>3</sup> )

**Comment [A19]:** Where are these estimated values in the table , what about clay and organic carbon values

Land use				
forest	1.42 <sup>a</sup>	1.34 <sup>a</sup>	5.96	5.79
cultivation	1.49 <sup>a</sup>	1.46 <sup>a</sup>	3.17	3.84
SE <sub>±</sub>	0.05	0.06	0.2	0.33
Cultivated slope				
upper	1.43	1.40 <sup>a</sup>	1.3	1.6
middle	1.46	1.40 <sup>a</sup>	4.2	3.2
lower	1.36	1.23 <sup>a</sup>	2.3	1.5
Forest slope				
upper	1.50	1.53 <sup>a</sup>	4.03	4.06
middle	1.46	1.43 <sup>a</sup>	4.5	5.53
lower	1.50	1.40 <sup>a</sup>	4.06	3.36
SE <sub>±</sub>	0.06	0.06	0.28	0.03

low mean values may be most vulnerable to wind erosion due to low dry stable aggregates (Ogunwale and Ogunleye, 2004). Increasing intensity of cultivation can reduce carbon rich macro-aggregates and increase carbon depleted micro-aggregates, resulting in an overall loss of soil organic carbon (Six *et al.*, 2000). ~~Conventional ploughing, which is commonly practiced in Afaka areas, causes damage to soil structure.~~ Noellemeyer *et al.* (2008) reported a loss of

**Comment [A20]:** Not relevant here

**Comment [A21]:** Sir, please stick to your results

intermediate aggregate size classes after long term cultivation with more pronounced negative effects of cultivation on macro aggregate size classes. This finding supports that the conversion of native forest to cultivation leads to deterioration of soil structure (Tisdall and Oades, 1980) as was applicable to Alfisols in Afaka forest reserve in Northern Guinea savanna of Nigeria.

**Comment [A22]:** No values , only theoretical discussion

Table 3: Effects of Land Use and Slope on electrical conductivity, Total Nitrogen, Available Phosphorus, Carbon/Nitrogen and Ratio Exchangeable Sodium Concentration, cation exchange capacity

**Comment [A23]:** No values in table

**Comment [A24]:** No values in table

	TN (g kg <sup>-1</sup> )	AP (mg kg <sup>-1</sup> )	NA (cmol kg <sup>-1</sup> )	CEC (cmol kg <sup>-1</sup> )
Land use				
forest	1.2	8.78	0.44	8.60
cultivation	1.1	5.4	0.45	8.54
SE <sub>±</sub>	0.01	2.1	0.04	0.5
Cultivated slope				
upper	1.1	9.60	0.43	7.93
middle	1.4	3.2	0.51	9.56
lower	0.9	13.4	0.41	8.13
Forest slope				
upper	1.4	8.82	0.39	9.00
middle	1.4	5.01	0.48	9.00
lower	0.9	2.45	0.43	7.80
SE <sub>±</sub>	0.41	2.57	0.05	0.60

EC = electrical conductivity, TN = total nitrogen, AP = available phosphorus, Na = sodium and CEC = cation exchange capacity.

### Total nitrogen

Total N contents were highly affected by the different land use systems. Total soil nitrogen at 0-10 cm depth had a mean of  $1.11 \text{ g kg}^{-1}$  under cultivated land, while  $1.2 \text{ g kg}^{-1}$  was recorded under natural forest land. The cultivated land had mean of  $0.9 \text{ g kg}^{-1}$ ,  $1.4 \text{ g kg}^{-1}$  and  $1.05 \text{ g kg}^{-1}$  of total nitrogen for upper, middle and lower slopes respectively, while forestland had mean of  $1.4 \text{ g kg}^{-1}$ ,  $1.4 \text{ g kg}^{-1}$  and  $0.9 \text{ g kg}^{-1}$  total nitrogen in upper, middle and lower slopes respectively (Table 3). 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 cultivated land and high under natural forest land use in Afaka northern guinea savanna of Nigeria. It is in agreement with the findings of 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 cultivated and farmers' 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) in forest soils have concentration of land use systems had mean values of  $8.78 \text{ mg kg}^{-1}$  but and  $5.47 \text{ mg kg}^{-1}$  for forest and cultivated land. The available Phosphorus in soils on lower slopes recorded have  $13.4 \text{ mg kg}^{-1}$  available phosphorus, followed but decreased to by upper slope with  $9.60 \text{ mg kg}^{-1}$  in soils on upper slopes and middle slope with  $3.2 \text{ mg/kg}$  in middle slopes of cultivated fields land. Forestland at upper slopes

**Comment [A25]:** BD and AWC are given at 0-5cm and 5-10cm but for TN why 10cm? where is justification for your results. Explain.



recorded 8.82 mg kg<sup>-1</sup> available phosphorus, followed by middle slope with 5.01 mg kg<sup>-1</sup> and lower slope with 2.45 mg kg<sup>-1</sup> in (Table 3). Thomas (2000) reported that natural forestland 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. Organic compounds in soils increase P availability by the formation of organophosphate complexes that are more easily assimilated by plants, anion replacement of H<sub>2</sub>PO<sub>4</sub> from adsorption sites, the coating of Fe/Al oxides by humus to form a protective cover and reduced phosphorus fixation (Thomas, 2000). Also, decomposing of organic matter releases acids that increase solubility of calcium phosphates (Ahn, 1993; Thompson and Troeh, 1993; Havlin *et al.*, 1999). Available P was positively correlated with organic carbon (Thomas, 2000).

Differences of slope gradient among the areas did not significantly ( $P > 0.05$ ) affect available P (Table 3). The lowest (4.12 mg kg<sup>-1</sup>) and highest (9.31 mg kg<sup>-1</sup>) contents of available P were recorded in soils of middle slope and upper slope terrains respectively (Table 3). Fisseha *et al.* (2014) also reported low available P within soils having low content of OM, but Nega and Heluf (2013) stated that available P content of Tropical soils did not necessarily decrease with decrease of organic matter. The low contents of available P observed in soil of the study area were in agreement with reports by some authors (Murphy and Lugo, 1986; that availability of P under most soils of savanna Alfisols decline by the impacts of fixation, abundant crop harvest and erosion.

**Cation exchange capacity (CEC):**

**Comment [A26]:** How these references are helpful in supporting your findings. Justify.

Forestlands recorded CEC value of 8.60 cmol kg<sup>-1</sup> compared to cultivated land with mean value of 8.54 cmol kg<sup>-1</sup> while the lower slopes in forestland showed decrease in CEC with 7.80 cmol kg<sup>-1</sup> and 9.00 cmol kg<sup>-1</sup> for upper and middle slope respectively. The upper slope of cultivated land showed decrease in CEC with 7.93 cmol kg<sup>-1</sup>, 9.56 cmol kg<sup>-1</sup> for middle slope and 8.13 cmol kg<sup>-1</sup> for lower slope (Table 3). 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 two land use types and slopes (Table 3). Cation exchange capacity (CEC) of the study area was not 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 erosion, nature of soils and low organic matter content of the soils.

**Comment [A27]:** Monotonous lines of expressing results

**Comment [A28]:** Generalized statement

**Comment [A29]:** How and why

**Comment [A30]:** This reference for bil environs of Brahmaputra valley but not for forest soils of hills.

### Soil pH (H<sub>2</sub>O) and CaCl<sub>2</sub>

The highest soil pH in water (pH 7.16) was recorded in Neutral pH os soils under -forestland and cultivated (pH 6.9) in cultivated land. The slope has subtle effect on pH of

**Comment [A31]:** Avoid using highest , state directly neutral pH for soils of

The upper slope had pH (H<sub>2</sub>O) 6.9 at upper and middle but lowered to , middle slope had pH (H<sub>2</sub>O) 6.9 and lower slope had pH (H<sub>2</sub>O) 6.8 in cultivated field at lower slopes . similar trends of pH for land, while forest soils land had pH (H<sub>2</sub>O) 7.2, 6.9 and 7.2 for upper, middle and lower slopes respectively are reported. Values of soil pH (CaCl<sub>2</sub>) were 6.49 and 6.22 for forest and cultivated land use types respectively. Upper slopes had pH (CaCl<sub>2</sub>) 6.13; middle slope had pH (CaCl<sub>2</sub>) 6.16 and lower slope had pH (CaCl<sub>2</sub>) 6.36 in cultivated land, while 6.5 pH (CaCl<sub>2</sub>), 6.3 pH (CaCl<sub>2</sub>) and 6.6 pH (CaCl<sub>2</sub>) values were recorded in forest land (Table 4). It however increased slightly down the topographic positions in soils of both cultivated and forested lands.

**Comment [A32]:** Revise this line

The generally increasing trends in pH value from middle to lower slope positions may be due to higher deposition of basic cations in lower slope positions. This agrees with Belay (1996),

	pH (H <sub>2</sub> O)	pH (CaCl <sub>2</sub> )
Land use		
forest	7.16	6.49
cultivation	6.90	6.22
SE <sub>±</sub>	0.1	0.12

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.

**Comment [A33]:** Rewrite

Table 4: Effects of Land Use and Slope on pH in water and in CaCl<sub>2</sub>

Cultivated slope		
upper	6.9	6.13
middle	6.9	6.16
lower	6.8	6.36
Forest slope		
upper	7.2	6.5
middle	6.9	6.3
lower	7.2	6.6
SE <sub>±</sub>	0.12	0.14

**Criteria for thresh hold limits for Soil Quality Monitoring and Evaluationassessment in Afaka reserve, Nigeria**

To monitor soil quality, treatment means for bulk density, mean weight diameter, pH in H<sub>2</sub>O and CaCl<sub>2</sub>, organic carbon, total nitrogen, available phosphorus, cation exchange capacity were matched as shown in the Table 5.

Bulk density shows that forest soil had the least bulk density 1.34 Mg m<sup>-3</sup> while cultivated land had the highest bulk density 1.46 Mg m<sup>-3</sup> (Table 5).

**Comment [A34]:** Why here? You already mentioned in materials and methods

Table 5 shows that mean weight diameter dry for forest soil (1.24mm) is greater than for cultivated land (1.19mm). The pH in H<sub>2</sub>O and CaCl<sub>2</sub> shows that pH decreased slightly under cultivation and increased under forest. Both pH in H<sub>2</sub>O and CaCl<sub>2</sub> followed the same trend.

Comment [A35]: Not listed in table

~~Table 5 shows that~~ there was increase in organic carbon contents under forest (10.2 g kg<sup>-1</sup>) while cultivated land show with decrease in organic carbon content of cultivated fields (8.21 g kg<sup>-1</sup>). Also, Table 5 shows that similar trends of a total N content of (1.2 g kg<sup>-1</sup>) was observed in the forest as against land, while cultivated land was with (1.1 g kg<sup>-1</sup>).

~~Table 5 shows that forestland had the highest content of available P of (8.78 mg kg<sup>-1</sup>) for forest to that of , Cultivated land had the least (5.47 mg kg<sup>-1</sup>) for cultivated, 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 cultivation (8.54 cmol kg<sup>-1</sup>) but, and slightly increased slightly with under forest cover ( 8.60 cmol kg<sup>-1</sup> ) in CEC would implying 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 lower slope had the least bulk density (1.37 Mg m<sup>-3</sup>) while upper had the highest bulk density 1.47 (Mg m<sup>-3</sup>) then 1.44 (Mg m<sup>-3</sup>) record in the middle slope, it's also shows that there was increase in organic carbon contents under middle slope 11.0 g kg<sup>-1</sup> fallowed by upper slope with 9.30 g kg<sup>-1</sup> then lower slope 7.40 g kg<sup>-1</sup>. Total N content of 1.20 g kg<sup>-1</sup> was observed at upper slope, 1.4 g kg<sup>-1</sup> and 0.9 g kg<sup>-1</sup> at middle and lower slope respectively.

Comment [A36]: Repeated twice check in manuscript

Table 5 shows that upper slope had the highest content of available P among the other slopes, 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 lower slope 7.97 cmol kg<sup>-1</sup>, 8.46 cmol kg<sup>-1</sup> at upper slope and increased under middle slope 9.28 cmol kg<sup>-1</sup>. Table 5 shows that lower slope increased in dry mean weight diameter with 1.32mm while upper slope had 1.22 mm. Lower slopes show least in wet mean diameter (1.19 mm) and upper slope (1.21mm), middle slope shows increase with (1.28 mm) table 5. It shows that pH in water decreased slightly under middle slope and increased under lower slope. Decrease in soil pH however, was not sufficient to hamper crop growth. Both pH in H<sub>2</sub>O and CaCl<sub>2</sub> 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 5.

**Comment [A37]:** Check it with

Table 5: Threshold limits for soil quality assessment in Afaka Alfisols Using Minimum Data Set

**Comment [A38]:** For forest and cultivated

Soil parameter	Forest	Cultivated land
Bulk density (Mg m <sup>-3</sup> )	1.34	1.46
Organic carbon (g kg <sup>-1</sup> )	10.2	8.21
Total nitrogen (g kg <sup>-1</sup> )	1.2	1.1
Available phosphorus (mg kg <sup>-1</sup> )	8.78	5.47
CEC (cmol kg <sup>-1</sup> )	8.60	8.54
Dry mean weight	1.24	1.19
Wet mean weight	1.27	1.19
pH (H <sub>2</sub> O (1:2.5))	7.16	6.90
pH (CaCl <sub>2</sub> ) (0.01M)	6.49	6.22

**Comment [A39]:** Unit of expression

**Comment [A40]:** Unit of expression  
Where is in methodology and earlier data sets

Table 6: Threshold limits for soil quality assessment in Afaka Alfisols.

Properties	upper	middle	lower
Bulk density ( $\text{Mg m}^{-3}$ )	1.47	1.44	1.37
Organic carbon ( $\text{g kg}^{-1}$ )	9.30	11.0	7.40
Total nitrogen ( $\text{g kg}^{-1}$ )	1.20	1.4	0.9
Available phosphorus ( $\text{mg kg}^{-1}$ )	9.31	4.12	7.94
CEC ( $\text{cmol kg}^{-1}$ )	8.46	9.28	7.97
Dry mean weight	1.22	1.11	1.32
Wet mean weight	1.21	1.28	1.19
pH ( $\text{H}_2\text{O}$ (1:2.5))	7.03	6.97	7.08
pH ( $\text{CaCl}_2$ (0.01M))	6.38	6.37	6.32

Comment [A41]: Are they mean values

Table 7: Threshold limits for soil quality assessment in Afaka Alfisols.

Properties	upper	middle	lower
Bulk density ( $\text{Mg m}^{-3}$ )	1.47	1.44	1.37
Organic carbon ( $\text{g kg}^{-1}$ )	9.30	11.0	7.40
Total nitrogen ( $\text{g kg}^{-1}$ )	1.20	1.4	0.9
Available phosphorus ( $\text{mg kg}^{-1}$ )	9.31	4.12	7.94
CEC ( $\text{cmol kg}^{-1}$ )	8.46	9.28	7.97
Dry mean weight	1.22	1.11	1.32
Wet mean weight	1.21	1.28	1.19
pH ( $\text{H}_2\text{O}$ (1:2.5))	7.03	6.97	7.08
pH ( $\text{CaCl}_2$ (0.01M))	6.38	6.37	6.32



## Soil quality evaluation

Soil of the land uses and slopes 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 slopes 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, upper forest soil had the highest score index followed by cultivated lower slope soil, cultivated upper, middle forest, forest lower and cultivated lower slope land respectively. The variation order of soil (upper forest>lower cultivated>upper cultivated>middle forest>lower forest>middle cultivated) indicate the direction of good quality of soil.

Comment [A42]: What is it, expand

Soil quality was assessed using a score scale of 1 to 6; where 1 is rated best and 6 rated worst. Thus; upper forest with highest total score was rated best, while middle cultivated with lowest total score rated worst. Upper forest scored best and enhance soil quality conditions (optimum soil organic carbon , total nitrogen , available phosphorus, potassium, EC, and bulk density), while middle slope cultivated lands were rated worst (low organic carbon, low k, moderate phosphorus, moderate nitrogen, low bulk density and electrical conductivity (Table 8)

### 4.5 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 soil quality evaluation for specific management practice (Anikwe 2006). Therefore soil quality rating is calculated by summation of weight scores for each of soil function.

**Comment [A43]:** This should be a part of methodology but not under results/discussion

Table 8: Soil Quality Monitoring and Evaluation in Afaka forest, Nigeria

Soil parameter	Soil of Afaka plantation		
	High	medium	low
Bulk density(Mg m <sup>-3</sup> )	≥ 1.4	1.2– 1.4	< 1.2
Organic carbon (g kg <sup>-1</sup> )	> 15	10 – 15	< 10
Total nitrogen (g kg <sup>-1</sup> )	0.3	0.2-0.3	<0.2
Available phosphorus(mg kg <sup>-1</sup> )	≥ 4.0	2.5 – 4.0	< 2.5
CEC(cmol kg <sup>-1</sup> )	>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 <sub>2</sub> O(1:2.5))	>5.5	4.8 – 5.5	< 4.8
pH (CaCl <sub>2</sub> )(0.01M)	>4.5	4.0 – 4.5	< 4.0

**Comment [A44]:** Unit of expression

**Comment [A45]:** Unit of expression

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

Table 9: combining indicators the scores into the index (SMAF protocol)

Functions	Indicators	F upper	F middle	F lower	C upper	C middle	C lower
Ease of tillage	Bulk density	0.015	0.014	0.015	0.014	0.014	0.013
Biological activities	Organic matter	0.12	0.12	0.123	0.087	0.096	0.06
Support plant growth	Total N	0.014	0.014	0.009	0.011	0.014	0.009
Support plant growth	Available p	0.08	0.05	0.024	0.096	0.032	0.134
Plant nutrient	CEC	0.09	0.09	0.078	0.079	0.095	0.081
Resistance to air erosion	Dry mean weight	0.012	0.012	0.013	0.012	0.010	0.013
Resistance to water erosion	Wet mean weight	0.013	0.010	0.013	0.01	0.015	0.010
Salinity	pH (H <sub>2</sub> O(1:2.5))	0.072	0.062	0.072	0.069	0.069	0.068
Salinity	pH (CaCl <sub>2</sub> (0.01M))	0.065	0.063	0.066	0.061	0.061	0.063
	Total (Index)	0.481	0.435	0.413	0.439	0.406	0.451

Table 10: Ranking of soil quality under different land use and slopes

Slope positions	Total score	Percentage	Ranking
F upper	0.481	48.1	1
C lower	0.451	45.1	2
C upper	0.439	43.9	3
F middle	0.435	43.5	4
F lower	0.413	41.3	5
C middle	0.406	40.6	6

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

### 5.1. Summary

The study was conducted with the aim to determine effect of land use on selected physical and chemical properties of Alfisols in Guinea savanna and to suggest management practices that would sustain croplands for sustainable productivity, conserve the environment and assess quantitatively, effect of forest and cultivation land uses on soil carbon stock. Rigid grid detailed survey plan was employed. Undisturbed core soil samples from depth of 0–5 cm (top soil) and 5–10 cm (lower layer) were collected at auger points determined along traverses from cultivated land and in adjacent forest, in each delineated geomorphic position of the study area for water

Comment [A46]: Irrelevant sentence

retention potential, and bulk density. Other soil samples collected were used for wet and dry aggregate stability determinations and selected chemical properties. The sampled area covered 1 km by 1 km dimension and the different locations were selected based on identified typical Afaka forest vegetation, typic toposequence and crop cultivated sites. Data collected was analyzed with SAS software (SAS, 1997) computer package to test for significant difference among treatments. In conditions where there was significant difference, mean comparison was performed with least significant different (LSD). However, saturated hydraulic conductivity and dry and wet aggregate stability were statistically not affected by these treatments ( $p < 0.05$ ). The results also show that soil moisture content was significantly affected ( $p < 0.05$ ) by land use type and slope and soil carbon stock show significant differences in land use type. The results also show no significant difference between these land use types and slope positions ( $p < 0.05$ ) on cation exchange capacity, total nitrogen, available phosphorus, Soil quality evaluation was based on the soil management assessment framework (SMAF) suggested by Andrews *et al.* (2004), scoring functions for 14 potential soil quality indicators (Wienhold *et al.*, 2009). and a minimum data set (MDS) was established. The MDS 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 were used as indicators for plant growth support, while organic carbon was indicator for biological activity in the soil, MWD was used to assess erodibility of the soils. Alfisol at the upper forest land had better soil quality than those at the slope positions. Slight change in CEC would imply that soil health/quality over the years had been positively impacted upon by the management practices.

**Comment [A47]:** No where mentioned the procedures in materials and methods

**Comment [A48]:** Where is soil carbon stock

**Comment [A49]:** Discussion not properly made

## 5.2. Conclusion

From the study, it was concluded that soil physico-chemical properties significantly varied among land use systems and slope positions in the study site. Shift in land use systems from natural forest to agricultural land use systems had detrimental effect on soil physical and chemical properties. The result indicates that organic matter concentration declined particularly in the upper slope of cultivated land, when compared to forest land. The result also indicates impact of forest on compaction of soils by the relatively high bulk density values recorded in soils under cultivated land use type on almost all the topographic positions. However, slope position affected most selected soil properties under different land use types considered in this study. The study indicates that cultivation led to increased bulk density, porosity and sodium content, reduced organic carbon, aggregate stability and water retention, total nitrogen, available phosphorus and potassium compared to forest land. The soil quality management should address the problem of land degradation which will help in mitigating the effects of climate change and global warming.

**Comment [A50]:** Revise after making suggestions

Forest soils have excellent potentials for sequestering organic carbon and maintaining or improving soil quality indicators; such as, bulk density, aggregate stability, soil moisture content, soil organic carbon and soil structure. Lower soil bulk density and pH levels, higher level of soil aggregation and lower susceptibility to wind and water erosion were observed on the cultivated land.

**Comment [A51]:** Revise it

## 5.3 Recommendations

It is recommended that integrated land management should be practiced such as practical soil conservation policies and measures to ensure sustainable use of soil as a resource to combat the

ongoing soil changes and improve soil fertility in different land use systems to overcome land degradation and achieve sustainable agricultural production in the study area.

Further studies involving longer term research and evaluation of land uses for carbon sequestration in soil aggregate fraction potentials, as well as socio-economics of the system is suggested. This would allow for better discernment of soil quality changes and cost benefits of the system.

Long-term experiments (10–30 years) should be conducted to establish the positive and negative effects of different land uses on soil indicators for developing models so that appropriate action could be taken accordingly

Comment [A52]: Revise it

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