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Physical Soil Quality of Semi - Arid Savanna as Influenced by *Acacia senegalensis* in Desert Research Experimental Plot Yobe State University Damaturu, Northern Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author HH designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors HGH and MB managed the analyses of the study. Author MB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Soil is a living and dynamic natural reservoir and source of plant nutrients that play numerous key roles in terrestrial ecosystems. This study investigated the impact of three adjacent land use systems (*Acacia senegalensis* plantation (ACP), *pilostigma raticulatum* plantation (PRP) and Ground nut field (GNF) on selected soil physical quality indicators in a Northern Nigeria semi- arid Savanna. Minimum data set for assessing soil quality (Prime quality agricultural land) in this study include bulk density, organic carbon content, total nitrogen, carbon stock, available phosphorus and pH values obtained from DRMCC research field. Mean values of the data set were arranged and scored to obtain totals among the minimum data set (MDS). Soil quality is considered a key element for evaluating the sustainability of land management practices. Data generated were analyzed using ANOVA and significant means were determined using Duncan multiple range test (DMRT). ACP had significantly higher organic carbon content (9.37 gkg^{-1}) and lower bulk density (2.16 gkg^{-1}) than *pilostigma* and GNF respectively. The lower bulk density (ρb) and high organic carbon in ACP might be due to high leaf shading by acacia while the lower bulk density in ground

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nut field aided by trampling induced compaction resulted in its high relative field capacity (RFC), permanent wilting point (PWP) and micro-p ore spaces (PMIC) tillage in ground nut field created loose soil in the plough layer (<20 cm) which turn out to its low bulk density (ρb). *Acacia* plantation contained highest total nitrogen value (1.23 gkg^{-1}); perhaps resulting *Acacia* leaf litter is known to have a high decomposition rate. *Pilostigma* plantation contained (1.22 gkg^{-1}) nitrogen, while the least nitrogen content was obtained under ground nut field. On scoring the land use types and depth against the minimum data set, the least total was that under *acacia* plantation, followed by pilostigma plantation then ground nut field. Therefore, soils under *acacia* plantation were ranked best quality (SQ1) for cultivation purposes at 0-10 cm, followed by *pilostigma* land use type that were ranked SQ2. Ground nut field soils were ranked least (SQ6) in quality for use in crop production at depth of 10-20 cm.

Keywords: Soil quality; Acacia senegalensis; plant nutrients; organic carbon content.

1. INTRODUCTION

Soil is a living and dynamic natural reservoir and source of plant nutrients that play numerous key roles in terrestrial ecosystems. For most agrarian settlements, the primary function of soil has been production of food, fodder, timber, fiber and fuel [1]. Plant roots penetrate and explore soil in order to acquire water, oxygen, nutrients and gain structural support for above-ground growth. Increase in food demand has resulted in the expansion and intensification of land use systems in the Nigerian Savanna. The intensification of land use systems in the Nigerian Savanna is facing increased abiotic pressure of which soil quality is among the most important. Shorter duration or absence of fallow, unsuitable crop rotation and inappropriate management practices have resulted in degradation of soil quality [2]. The region is characterized by high annual average temperature (28-32°C), short wet season and long dry season (6-9 months), abundant short grasses (<2 m) and a few scattered trees [2]. Most Nigerian Savanna soils are highly weathered and fragile with low activity clays, thus making their fertility decline under continuous arable cropping [2,3]. Generally, soil productivity declines rapidly when vegetation cover is lost and inappropriate management practices are adopted [2], thereby resulting in soil organic matter depletion and reduced agricultural productivity and food security. Population increase and the need to achieve food security; especially in Nigeria, has given rise to clearing of forests for agricultural land use [4]. Tropical soils are inherently fragile and therefore, sensitive to land use and management since removal of soil cover and subsequent tillage are activities that are likely to affect soil physical and chemical properties and micro aggregate stability [5].

Soil quality degradation, which can be defined as increasing inability of a soil to perform its ecosystem functions, is manifested in persisting problems of erosion, compaction, acidification, organic matter losses, nutrient losses, desertification and chemical contaminations which reduce agricultural production capacity and food security [6]. Eleven percent of vegetative area and 38 percent of cultivated area of the world have been classified as degraded since 1945. 12 percent of potential agricultural land has been severely degraded, 18 percent has lost substantial productivity and 0.5 percent has become unsuitable for cropping. Comparably in Nigeria, human induced soil degradation is a common phenomenon, where the severity is light for about 37.5 percent and high for 27.9 percent of the total area [7].

Soil quality is considered a key element for evaluating the sustainability of land management practices [8]. Numerous physical, chemical and biological properties can be used as indicators for assessing the effect of ecosystem disturbance by human activity on soil quality [9]. Although these properties are interdependent, soil physical quality strongly affects water availability, nutrient adsorption, aeration, rooting ability and thus crop performance; therefore it plays a central role in studies on soil quality [10]

A minimum data set (MDS) of soil factors has been proposed by Larson and Pierce [11] and it is generally accepted that such factors should be easy to calculate and present differences in management. Minimum data set (MDS) was proposed to measure soil quality and its changes due to management practices through selection of key indicators such as organic matter, pH, nutrient status, bulk density and rooting depth [11]. It is a minimum set of indicators required to obtain a complete understanding of the soil indicators examined. Collecting an MDS helps to identify relevant soil indicators and correlate them with significant soil and plant properties. Moreover, they provide a useful tool for evaluating the status, health and quality of soil [11,6,12]. Sufficiently detailed experiments need to be conducted to develop meaningful assessments of soil status, often expressed as an index 15 of soil quality [2]. When measurements are taken, values are subjected to the standardization procedure called scoring function, which, according to Oluwasemire and Doran [13,6] involves the conversion of measured value to unit-less values usually between 0 and 1. There are four general types of scoring functions used in soil quality assessment;

1. More is better (higher measurement means higher soil quality e.g soil organic matter),
2. Less is better (lower measurement means higher soil quality e.g bulk density),
3. Optimum range (moderate range of values is desirable, e.g pH),
4. Undesirable range (a specific range of value is undesirable) [13,6].

The study of soil response to different management systems provide valuable information concerning the practices that can improve quality of these soils.

A general outline is necessary to evaluate soil quality. That outline can be used to check changes in the environment associated with agricultural management.

1.1 Objectives

The overall goal of the current research was to evaluate the effect of cultivation of *Acacia senegalensis* ground nut and *Piliostigma reticulatum* on soil quality indicators with the aim of contributing to current efforts being made toward recommendation of best agronomic options for acacia production and its soil rehabilitation potentials in the semi-arid region.

The specific objectives were

I. To determine the effect of *Acacia senegalensis,* ground nut and *Piliostigma reticulatum* plantation on soil physical quality of semi-arid region Nigerian.
II. To determine the effect of acacia production and its soil rehabilitation potentials in the semi-arid region.

2. MATERIALS AND METHODS

2.1 Physical Setting of the Study Area

2.1.1 Location

The research was conducted at the desert research experimental plot Yobe state university Damaturu, Nigeria located at coordinates N11^0 40.788, E11^0 56.966 and N11^0 40.8584 E11^{0}56.923, andN11^0 40.772E 11^{0}56.908and 686 m above the sea level The area is situated in the Northern sahel Savanna agro-ecology of Nigeria with a monomodal rainfall pattern and long-term mean annual rainfall of about 1011±161 mm concentrated almost entirely in five months (May/June to September/October) and mean daily temperature of 24^0 C [12]. A total rainfall of 877.3 mm, 26.5^0 C mean daily temperature and 46.3 % mean daily relative humidity were recorded in the research year 2011.

2.1.2 Geology and soil

The soils can generally be described as varying in texture from sand in the upper horizons to sandy clay at the depth of 20-30 cm.

2.1.3 Plantation description

The plantation were: (a) *acacia senegalensis* plantation (b) Ground nut field (c) *Pilostigma raticulatum*. Other dominant shrubs and grasses which had been under natural vegetation for more than ten years are: *Cyperus rotundus* L., *Andropogon gayanus* L., *Loudetia annua*, and *Guera senegalensis*.

2.2 Soil Sampling Procedures

Disturbed soil samples obtained from the 0-10 and 10-20 cm depths were air-dried, sieved through 2 mm sieve and the less than 2 mm fractions were analyzed for soil pH, particle size distribution, organic carbon, carbon stock (SOC), total nitrogen, available phosphorus. Undisturbed core samples were obtained using 5 cm by 5 cm cores and analyzed for bulk density.

Particle size analysis of soil samples was used to determine percentage of sand, silt and clay in the soil samples. These percentages were used to determine textural classes of soil samples. The analysis was performed using the hydrometer method [7]. Textural classes were obtained from textural triangle using the [8].

A blank of the reagent was run and percentage of clay, silt and sand to be determined as follows:

$$\% \, Cla = \frac{Correction \; 2 \; hours \; hydrometer \; reading \times 100}{Weight \; of \; soil \; taken}$$

$$\% \, Silt = \frac{Corrected \; 40 \; seconds \; hydrometer \; reading \times 100}{Weight \; of \; soil \; taken}$$

$$\% \, Sand = 100 - (\% \, Silt \; + \% \, Clay)$$

$$Corrected \; reading \; C = (Actual \; reading - Blank \; reading) + \; 0.36T$$

Where T is the room temperature minus 20^0C

2.2.1 Determination of particle density

Particle density was determined using the Stan Stan pycnometer method using water and soil as determined by Anikwe [14] using formular

$$\rho_p = \frac{d_w \times w_1}{w_1 - (w_2 - w_3)}$$

Where ρ_p is the particle density (Mgm^3), w_1 is the weight of oven dried soil, w_2 is the weight of pycnometer + soil + water, w_3 is the weight of pycnometer + water and d_w is the density of water(Mgm^3) at room temperature.

2.2.2 Dry sieving

Dry aggregate size distribution was determined by dry sieving. Two hundred grams (200 g) of soil from each of the land use systems was passed through a set of sieves with diameter ranging from 5 mm-0.05 mm mounted on a CSC scientific sieve shaker. The sieve was arranged in descending order of diameter from top to bottom, the <0.05 mm soil aggregates was collected in the collecting pan placed below all other sieves. The nest of sieves was shaken for 60 seconds and soil aggregates retained in each sieve was collected and weighed. The aggregate size stability characterized by mean weight diameter (MWD) is defined according to Blake [15] as

$$MWD = \sum_{i=1}^{n} x_i \omega_i$$

Where

x_i = mean diameter of any particular size range of aggregate separated by sieve
ωi = weight of aggregate in the size range as fraction of the total dry weight of sample
n = number of aggregates in a size class
i= individual separate which is equal to 1

Soil structural index (SI) was estimated according to Reynolds et al. [4] as:

$$SI = \frac{1.724 \times \%OC}{\%Silt + \%Clay \times 100}$$

2.2.3 Determination of bulk density

Bulk density determination in each plantation was according to Kowal, Gregorich [16,9] as

$$V \;\; = \pi r^3 h$$

Where V volume of the core (cm^3) is, r is the radius (cm), h is the height of the core and π is 3.142

Bulk density was calculated as:

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

2.2.4 Porosity and pore size percentage

Total Porosity was obtained from the particle and bulk density determined for each geomorphic position and land use system. It was calculated as:

$$Porosity \, (\%) \;\; = \;\; \frac{particle \; density - Bulk \; density}{particle \; density} \times 100$$

2.2.5 Determination of soil pH

Soil pH of each soil sample obtained from auger points was determined both in water and 0.01MCaCl2 solution, using a soil to solution ration of 1:2.5 [9].

2.2.6 Organic carbon

Soil organic carbon was determined by the Walkley-Black wet oxidation method [10].

Organic carbon (OC) (g/kg) = OC (%) ×10

The carbon stock (SOC) in each agro ecological system was calculated the formula = C (gkg-1)/100 × soil bulk density × area (1 ha) × soil depth. Soil organic carbon 58 (SOC) stock was determined as a product of soil carbon of each depth, multiplied by depth, bulk density and 10000m2 and divided by 1000 i,e.,

SOC= Org (C × D × BD × 10000)/1000 (t C ha-1) where d = C = organic carbon concentration (gkg-1) Bd = bulk density at the depth (Mgm-3depth).

Where SOC = carbon stock of soil (t C ha-1) Org), 10,000m^2 =1ha, and 1000kg=1ton [13].

Electrical conductivity (EC) was determined using conductivity Meter Bridge at 1:5 soils: water ratio. The reading was multiplied by 6.4 [13] to obtain electrical conductivity (EC dS/m) of the soils.

Soil quality evaluation was based on soil management assessment framework suggested by Andrews et al. [17] with scoring functions for 14 potential soil quality indicators [16]. The minimum data set (MDS) selected in this study include soil functions such as support for plant growth; i.e., bulk density (BD), pH, CEC, total N, and available Phosphorus. Organic carbon and carbon stock were indicators for biological activity in the soil. Indicator ratings were divided into three groups; more is better was applied to N, P, CEC, SOC and organic matter, while less is better was applied to bulk density and optimum is better was applied to pH [11]. Data obtained was subjected to Analysis of Variance (ANOVA), using Generalized Linear Model (GLM) procedure of SAS 9.3 Software [15]. Differences between means were separated using Duncan Multiple Range Test (DMRT) at 5% level of probability.

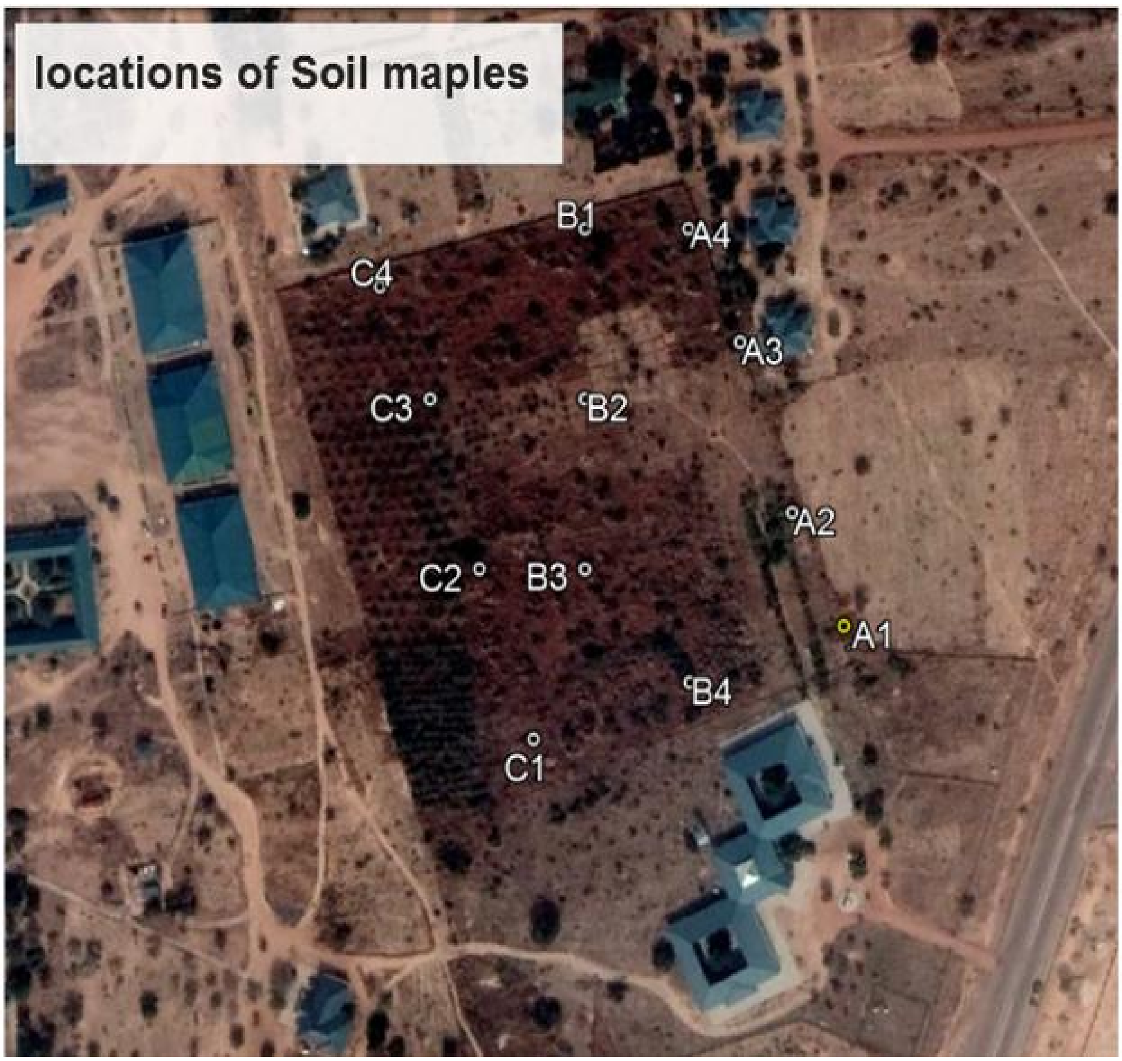

Fig. 1. Showing the Study area drmcc damaturu

3. RESULTS AND DISCUSSION

The results for particle size distribution, structural index (SI) and bulk density (*ρ*b) are provided in Table 1. The three land use systems (*pilostigma raticulatum*(PP), ground nut field (GNF) and acacia plantation (ACP) did not demonstrate significant variation in clay, silt and sand contents, where all the three land use systems have a loam textural class. Similar textural class (loam) was likewise identified in all the sampled soil depths with silt content significantly decreasing with depth and increase in sand and clay with depth [16]. The loamy texture of the fields indicates a moderately coarse nature of the soils. The increase of clay content with depth shows downward eluviation of clay from overlaying eluvial. A horizon to the underlying illuvial B horizon bulk density (*ρ*b) was statistically ($p \leq 0.05$) higher in GNF (1.35 Mg m−3), followed by ACP (1.34 Mg m−3) and lowest in PP (1.32 Mg m−3), suggesting perhaps, that crusting/surface sealing due to higher silt content in cultivated areas, trampling, cultivation [2] could have resulted to the higher bulk density values obtained in the cultivated areas there is increase in bulk density with depth 1.26 Mg m−3 at 0-10cm and 1.33 Mg m−3 at 10-20cm which might due to residue at upper surface. Porosity show little decrease between the land use 59.96% in PP and 59.06% in GNF and lower in acacia field, also exhibit decrease in depth 60.6 % and 57.33% at 0-10cm and 10-20cm depth respectively.

The structural index (SI) as a measure of structural degradation of soil did not significantly differ between the three land use systems, where all the values fell below the optimal range of 7%. Low values of SI observed in this study indicate structurally degraded condition of the fields [18]. One of the probable reasons for low SI was sub-optimal level of organic carbon observed in all the land use systems.

Total nitrogen content of soils in the acacia plantation (1.23 gkg-1) was significantly higher than those in in pilostigma (1.22 gkg-1) and ground nut field (1.20 gkg-1). The higher amount of total N concentration in the Acacia plantation was the ability of the plant to fix atmospheric N [19,20]. Acacia has N-fixing ability through a symbiotic relationship with bacteria in its root nodules, so they can produce leaves that are more N-rich than other tropical leguminous trees [20]. This capability of Acacia trees results in a substantial input of N-enriched litter, which can lead to increased soil N concentrations [20].

The study showed soil pH as the most influential variable in the Acacia and pilostigma are the same *Acacia* plantation (6.9) higher in ground/nut plot (7.0). The pH for all the plantations was within accepted ranges for the land use. *Acacia* plantation were found be more acidic than those plots in groundnut plot which had a mean pH of 6.9 in DRMCC research field [21]. The soil acidification in the *Acacia* plantation and pilostigma plantation was probably caused by a decrease in the concentrations of exchangeable cations or bases in soils and it was presumed to be due to translocation of base cations from soil to plant biomass [22] or leaching of nutrients [17].

The generally low concentrations of available phosphorous (6.89) in the g/nut field. The Acacia plantation (8.9), 8.88) in pilostigma plantation could be due to plant uptake and sequestration of P in the tree biomass [23] or nutrient leaching in the sandy soils. Additionally, Fisher and Binkley [24] state that the low available P in soil correlates with the acidic pH and as shown in this study, soils from the Acacia plantation and the HF were very acidic, so available P in the soil could be very limited.

Acacia plantation soils had a significantly greater organic matter content (9.37 gkg-1) than those of the pilostigma plantation (9.36 gkg-1) (Table 2). However, OM content did not differ between the soils in the Acacia plantation and pilostigma plantation ($P > 0.05$, Table 2).The presence of herb and understory layer in the acacia and pilostigma provided shading, which contributes to the modification in temperature regimes and high moisture content leading to a decline in the decomposition rate [25].

The OM content can impact the water absorption capability at the soil surface, for example, low OM content can increase water leaching or surface run-off resulting in low soil moisture content [26]. An increase in OM content could subsequently lead to an increase in soil fauna and greater pore space, thus making water to infiltrate more readily into and be held in the soil [27].

Table 1. Influence of land use and depth on particle size distribution, structural index, porosity and bulk density

Treatment	Sand (%)	Silt (%)	Clay (%)	Structural index (%)	Porosity (%)	Bd(Mgm^{-3})
Land use						
Pilostigma plantation	49.17	14.66	13.67	1.07	59.96	1.32^{ab}
G/nut field	4950	13.83	12.24	1.14	59.06	1.35^{a}
Acacia plantation	50.66	15.66	14.16	1.13	55.20	1.34^{a}
Depth						
0-10cm	55.10	15.83	12.33	1.30	60.06	1.26^{a}
10-20cm	52.33	14.56	14.00	1.03	57.33	1.33^{b}
SE	0.99	1.80	1.13	0.15	4.23	0.02

BD= bulk density

Table 2. Influence of land use and depth on particle density, carbonate, pH, total nitrogen, organic carbon, soil carbon stock and available phosphorous

Treatment	Pd (Mgm^{-3})	Carbonate	pH	TN ($mgkg^{-1}$)	Ec	Oc (gkg^{-1})	Soc (kg ha^{-1})	AP($mgkg^{-3}$)
Land use								
Pilostigma plantation	2.26^{b}	9.17	6.9	1.22	0.03	9.36	2020.0	8.88
G/nut field	2.23^{a}	6.3	7.0	1.20	0.03	9.10	1873.3	6.57
Acacia plantation	2.16^{a}	8.56	6.9	1.23	0.04	9.37	1914.3	8.9
Depth								
0-10cm	2.26^{a}	6.17	6.9	1.22	0.03	9.57	1913.3	8.7
10-20cm	2.23^{a}	6.66	6.8	1.20	0.04	9.40	1883.0	7.6
SE	0.03	1.37	0.03	0.41	3.07	0.51	102.05	2.57

Pd= particle density, TN = total nitrogen, EC= electrical conductivity, OC= soil organic stock and AP= available phosphorus

Table 3. Mean values adopted for soil quality assessment in DRMCC research field

Functions	Indicators	Pilostigma plantation	G/nut field	Acacia plantation	0-10cm	10-20cm
Ease of tillage	Bulk density	1.32(4)	1.35(1)	1.34(2)	1.26(5)	1.33(3)
Biological activities	Organic matter	9.36(4)	9.10(5)	9.37(3)	9.57(1)	9.40(2)
Support plant growth	Total N	1.22(2)	1.20(3)	1.23(1)	1.22(2)	1.20(3)
Support plant growth	Available p	8.88(2)	6.57(5)	8.9(1)	8.7(3)	7.6(4)
Salinity	pH (H_2O(1:2.5)	6.9(2)	7.0(1)	6.9(2)	6.9(2)	6.8(3)
	Total (Index)	14	15	9	13	15

Table 4. Soil quality ranking for DMRCC land use and depth semi-arid savanna Nigeria parameters

Functions	Indicators	Pilostigma plantation	G/nut field	Acacia plantation	0-10cm	10-20cm
Ease of tillage	Bulk density	4	1	2	5	3
Biological activities	Organic matter	4	5	3	1	2
Support plant growth	Total N	2	3	1	2	3
Support plant growth	Available p	2	5	1	3	4
Salinity	Ph (H_2O(1:2.5)	2	1	2	2	3
	Total (Index)	14	15	9	13	15
	Ranking	3	4	1	2	4

Table 5. Summary of criteria for soil quality monitoring and evaluation in DRMCC research field, Yobe State University

Soil parameter	Soil of DRMCC		Research field
	High	medium	low
Bulk density(Mg m^{-3})	> 1.45	-	< 1.25
Organic carbon (gkg^{-1})	>10.25	8-1.25	<8
Total nitrogen (g kg^{-1})	>2.0	1.5-2.0	<1
Available phosphorus(mg kg^{-1})	>20	10 – 20	0-10
pH (H_2O(1:2.5)	>5.5	4.8 – 5.5	< 4.8

Carbon stock in pilostigma plantation (2020 kg ha^{-1}) and acacia platation (1914.3 kg ha^{-1}) was significantly higher than Ground nut field types (1873.3 kg ha^{-1}) perhaps due to forest biomass accumulation and decomposition (Table 2). In cultivated land use type, higher rates of mineralization arising from cultivation activities would account for reduced carbon stock recorded [2,11].

Mean values of the data set were arranged (Table 3) and scored to obtain totals among the minimum data set (MDS). Prime quality agricultural land is a limited resource defined as soils with the necessary qualities to produce high crop yields when properly managed [28]. The least bulk density value (1.32 Mgm^{-3}) was obtained from polistigma plantation; suggesting that soils in *polistigma raticulatum* plantation were least compacted than GNF (1.35 Mgm^{-3}) and ACP (1.34 Mgm^{-3}). Bulk density is also lower at 0-10cm (1.26 Mgm^{-3}) compared to 10-20 cm with (1.33 Mgm^{-3}) depth. Suggesting that soil in this land use type were more compact, resulting from effect of cultivation, crust and soil erosion (Lal 1996). Organic carbon content was highest at acacia plantation (9.37gkg^{-1}), followed by *polistigma* (9.36 gkg^{-1}) and then ground nut field land use type (9.10 gkg^{-1}). With 0-10cm (9.57 gkg^{-1}) and lower at 10-20 cm (9.40 gkg^{-1}).

Acacia plantation contained highest total nitrogen value (1.23 gkg^{-1}); perhaps resulting from *Acacia* leaf litter is known to have a high decomposition rate [28]. *Pilostigma* plantation contained (1.22 gkg^{-1}) nitrogen, while the least nitrogen content was obtained under ground nut field (Table 3). On scoring the land use types and depth against the minimum data set, the least total was under acacia plantation, followed by pilostigma plantation then ground nut field (Tables 3 and 4). Therefore, soils under acacia platation were ranked best quality (SQ1) for cultivation purposes at 0-10 cm, followed by pilostigma land use type that were ranked SQ2. Ground nut field soils were ranked least (SQ6) in quality for use in crop production at depth of 10-20 cm (Table 4).

4. CONCLUSION

From the study, it was concluded that soil physico-chemical properties significantly varied among land use systems. This has shown that *Acacia* trees have the ability to change some soil physico-chemical properties when compared to native and tropical *pilostigma raticulatum* forests. The study indicates that cultivation led to increased bulk density, porosity, reduced organic carbon, aggregate stability. It was found that the soils in the *acacia senegalensis* plantation had a significantly higher organic carbon and total Nitrogen content than in other land use. The N-fixing ability of the *Acacia* trees produced nitrogen resulting from *Acacia* leaf litter is known to have a high decomposition rate. The result indicates that organic matter concentration declined particularly in the ground nut land. *Acacia and pilostigma* soils have excellent potentials for sequestering organic carbon and maintaining or improving soil quality indicators; such as, bulk density, aggregate stability, soil organic carbon content 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 ground nut field under cultivation. Therefore, soils under *acacia senegalensis* platation were ranked best quality (SQ1) for cultivation purposes at 0-10 cm, followed by *pilostigma raticulatum* land use type that were ranked SQ2. Ground nut field soils were ranked least (SQ6) in quality for use in crop production.

5. 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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