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INFLUENCE OF TREE PLANTATION GMELINA ARBOREA AND GLIRICIDIA SEPIUM ON SOIL PHYSICO-CHEMICAL PROPERTIES IN ABAKALIKI, SOUTHEAST, NIGERIA

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ABSTRACT

The study examined the influence of the two most prominent exotic species in Abakaliki, southeast, Nigeria and the nutrient accumulation on the soils. The plantations species were Gmelina arborea (Gmelina) established in 1988 and Gliricidia sepium established in the same year. The treatments were: Gmelina Plantation Area (GmPA), Gmelina Free Area GmFA, Gliricidia Plantation Area (GlPA), Gliricidia Free Area GlFA. The experiment was established as a Randomized Complete Block Design (RCBD) with four (4) treatments replicated six (6) times. Ground-truthing survey was carried out using a Geographical Positioning System (GPS) and the point data were keyed in into arc GIS software to delineate the study area. The Gmelina and Gliricidia plantation areas and their respective free areas were mapped into 6 plots, and on each plot, sampling points were randomly established, soil samples were taken using soil auger within 0-20cm soil depth. The overall results of exchangeable bases of the soil indicates that calcium (Ca), magnesium (Mg), cation exchange capacity (CEC), base saturation (BS), exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) differs significantly ($P<0.05$). However, potassium (K) and sodium (Na) did not differ significantly ($P>0.05$) from the influence of Gmelina and Gliricidia plantations. Our study further revealed that influence of tree plantation on physical properties showed significant difference ($P<0.05$) on sand, silt, clay, bulk density and gravimetric moisture content (GMC) except for total porosity which did not differ significantly ($P>0.05$). Tree plantation and biodiversity conservation ensure sustainable management of natural forest resources. Participation of NGOs and private individuals in plantation development could also be enhanced through the organized taungya farming system and other forms of tree planting like agroforestry system for improved soil conservation and restoration of degraded lands.

KEYWORDS

Agroforestry; Biodiversity; Biomass; Landuse; Soil Quality; Plantation.

1. INTRODUCTION

Good knowledge of the prevailing soil properties in addition to sustainable management of the soil enhances the capacity of the soil to function effectively in providing ecosystem services in view of ensuring increase in soil fertility and decline in soil degradation [1, 2].

Penetration of deep roots into the soil profile passing through the topsoil to the subsoils layers tends to increases the root inputs of the soil [3,4]. Release of root exudates by roots enhances formation of soil organic matter, while the efficient utilization of exudates by microorganisms through the conversion of root exudates to biomass and secondary by-products contributes to effective soil stabilization and retention of soil minerals [5-7]. Furthermore, the mycorrhizal type of deep roots is a key driver in the accumulation of soil organic carbon within the rhizosphere [8,9].

Establishment of tree planting programmes in view of ensuring environmental and biodiversity conservation is recently gaining relevance and international recognition, with the aim of countering adverse effect of natural disasters and ensuring environmental sustainability [10,11]. The soil remains the treasure base of agriculture and also a pivotal base and home of terrestrial ecosystems. Humanity depends on terrestrial ecosystem services, which supports C stabilization and regulation aimed towards mitigation of adverse effects of climate change for sustainable and livelihood. The role of the soil includes: providing base and physical support for effective plant growth, nutrient and mineral supply for biomass production, biodiversity conservation and provision of ecosystem services for mankind [12,13]. Sustainable afforestation is promoted with the planting of environmental-friendly trees that supports soil improvement and provision of ecosystem and ecological services [14]. Fast growth rate and potential of high biomass production within a very short-time period is the unique characteristic of many tropical forest plantation. Tropical tree plantation species has the potential of producing higher biomass per hectare compared with natural forests trees [15]. Gmelina and Gliricidia are deciduous tree species of the Lamiaceae and Fabaceae family respectively. West African countries of Nigeria, Sierra-Leone and Ghana play host to both Gmelina and Gliricidia were they are mainly grown as exotic species in plantations across different landscapes, whereas the paper and pulp industries basically grow Gmelila for the sloe aim of providing raw materials for the industry. However, serious concern has been raised regarding the physico-chemical and biological sustainability of plantation sites [16]. Eucalyptus tereticornis plays a vital role in the improvement of soil physico-chemical properties in the plantation area while Gmelina arborea plantation has been shown to be good soil modifier in terms of stabilization of soil nutrients [17].

In the study area, and Nigeria in general, land use land cover change remains an issue of great concern due to the erection of developmental structures by both the State and Federal Governments, leading to significant decline in forest/plantation cover and pronounced soil degradation as well severe soil erosion as can be observed in different parts of Nigeria. A conservative assessment in southeastern Nigeria indicates the following distribution trend for gully sites at various development stages: Abia (300), Anambra (700), Ebonyi (250), Enugu (600) and Imo (400) [18]. However, the statistics are not entirely exhaustive enough as new sites are developing during each rainy season due to tree felling in unsustainable manner which have hampered soil management practices in the study area. Erosion predominates in this area (southeastern Nigeria) and this is mainly as a result indiscriminate felling of trees and burning of bushes, continuous cropping and mining across landscapes without due consideration for environmental sustainability [19].

Soil loss in southeastern Nigeria gives rise to loss of ecosystem services, decline in soil fertility, soil structural degradation, sharp decline in soil biodiversity population, and severe decrease in both crop and agricultural productivity, low agricultural income, hunger, food insecurity and food insufficiency leading to social unrest [20,21]. Adequate storage of soil nutrients and its subsequent release in available forms (e.g. available N, available P, and available K) is a good indicator of soil fertility [22].

However, precise data on the addition of nutrients to the soil by legumes such as Gmelina arborea and Gliricidia sepium under Abakaliki tropical climatic conditions are inadequate. According to a study southeastern soils are low in organic matter content, base status and water storage capacity with high susceptibility to accelerated erosion and land degradation [23]. Therefore, build-up of these nutrients in soils of the study area through plantation of trees such as Gmelina and Gliricidia through its nitrogen fixation processes is important. However, assessing and quantifying soil physicochemical properties variation and pattern under *Gmelina and Gliricidia* plantation in the study is very important in view of ensuring sustainable management of native vegetation across landscapes for conservation and ecosystem rehabilitation in Abakaliki. More so, study of this nature has not been carried out previously in the study were deforestation and soil fertility decline is on the increase. These and more are the gaps this study aims to fill and address.

The objectives of this study were to assess the performance of two major afforestation tree species (*Gmelina arborea* and *Gliricidia Sepium*) in Abakaliki, southeast, Nigeria and to document the present nutrient status of the plantation soils. The study also aimed to assess the effects of plantation areas on soil physico-chemical properties in tropical derived savannah zone of Abakaliki, southeastern, Nigeria.

2. MATERIALS AND METHODS

2.1. Experimental Site

The research was conducted at the Ebonyi state Agricultural Development Programme Gliricidia farm and Ebonyi state reserve Gmelina plantation, both in Abakaliki Southeast, Nigeria (Figure 1). The locations fall within longitude 6° 45'N and latitude 8° 65'E in the tropical rainforest of derived savannah zone of Southeastern Nigeria.

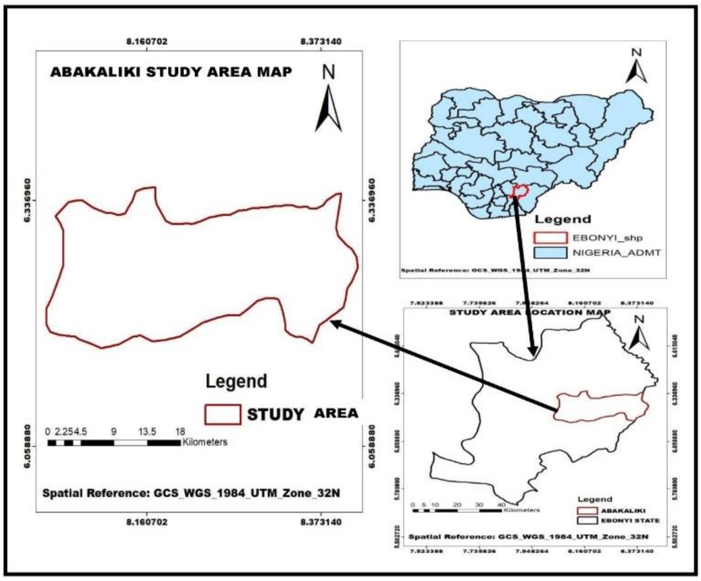

Figure 1: Map of the Study Area

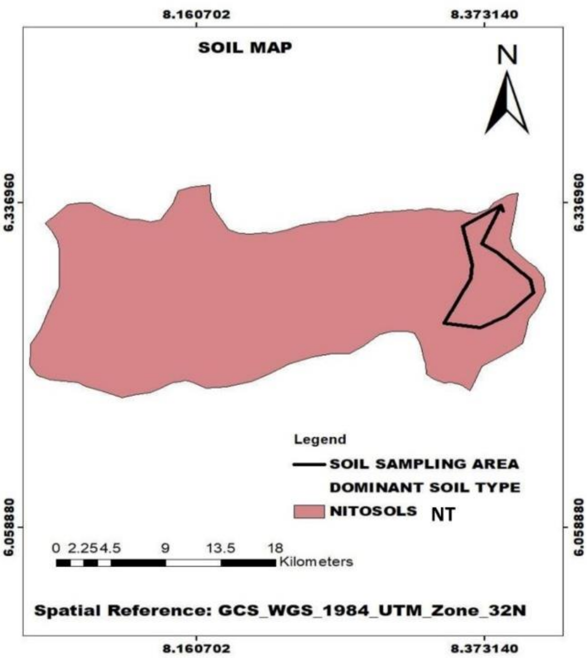

Figure 2: Soil Map of the Study Area

2.2. Experimental Design

The experimental set-up was as a Randomized Complete Block Design (RCBD) with four (4) treatments and replicated six (6) times. This experimental design was chosen because the experimental units are essentially homogeneous and the only source of variation is the treatments. The treatments were: Gmelina Plantation Area (GmPA), Gmelina Free Area GmFA, Gliricidia Plantation Area (GlPA), Gliricidia Free Area GlFA. Twenty-nine-year-old Gmelina and Gliricidia stands were used, being the recommended rotation age for its timber. Ground-truthing survey was carried out using a geographical positioning system (GPS).

2.3. Geology, Soil and Climate

The soil of the study area originates from sedimentary rock. The area is also marked by two significant angular unconformities; one inter formational between the Asu River Group and Ezeaku Formation, and the other intraformational within the Ezeaku Formation [24]. It has undulating topography with an elevation that range from 19 to 100 above sea level representing low and high surface areas respectively (Figure 3). The soil of the study area belongs to one dorminant soil groups type Nitosols (NT) [25]. Soil map of the area was generated by overlaying the vector shape file of the study area with World Soil Reference Base map raster file and then extracted by mask using spatial analysis tool in ArcGIS environment (Figure 2). The rainfall in the area range between 1200mm-2000mm and experiences a bimodal pattern of rainfall (April-July) and (September –November) with short spell in August known as "August break" [26]. The minimum temperature is 27°C while the maximum temperature is 31°C. During the rainy season, relative humidity is about 80% but rescinds to 60% during dry season [27].

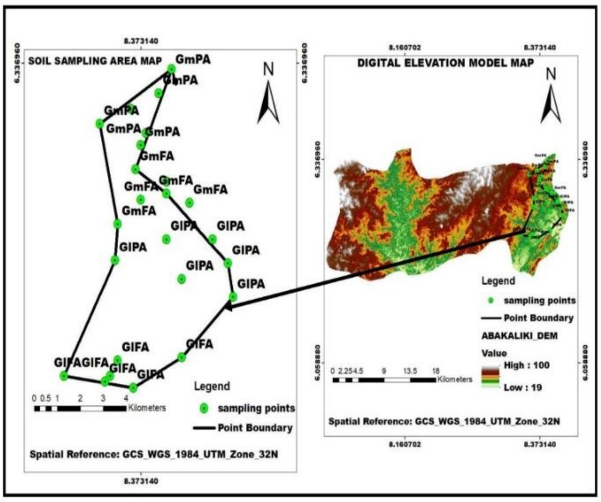

Figure 3: Soil sampling Areas in Abakaliki

2.4. Soil Sampling

The Gmelina and Gliricidia plantation areas and their respective free areas were mapped into 6 plots, and on each plot, sampling points were randomly established, and soil auger was used in collecting soil samples within 0-20cm soil depth. The sample from each plot were mixed together to form a composite soil sample, and a subsample taken for laboratory analysis (Figure 3). The same procedure was replicated for both free Gmelina and free Gliricidia area 100m away from each plantation (Gliricidia and Gmelina). Total of 24 soil samples were collected from Gmelina and Gliricidia plantation areas with their respective free area (control), six samples on each plantation areas. However, the majority of the soil sampling area falls in low elevation areas making it more prone to flooding.

2.5. Laboratory Analysis

The whole soil analysis were done in the Soil Science Laboratory of Ebonyi State University, Abakaliki, Nigeria

2.6. Soil Physical Properties

Particle size distribution was determined and analyze for as described by Bouyoucos hydrometer method, using sodium hexametaphosphate (calgon) as dispersant [28]. Bulk density was determined using method [29]. Total porosity and gravimetric moisture content were determined according to the method [30].

2.7. Soil Chemical Properties

The soil samples were air-dried and carefully sieved with 2mm diameter mesh. Soil pH was determined potentiometrically using pH meter in a soil:solution ratio of 1:2.5. Thereafter, standard laboratory techniques were used in determining selected soil chemical properties. Total nitrogen was determined using micro-kjedhal procedure [31]. Phosphorus was determined using the Bray-2 method [32]. Exchangeable sodium and potassium were determined using flame photometry method [33]. Exchangeable calcium and magnesium were determined using the titration method [34]. Organic carbon was determined according to the procedure [35]. Results on organic matter content was obtained by multiplying the soil organic C content by 1.724 (the van Bernmelen factor). Cation exchange capacity was determined using ammonium acetate (NH_4OAC) displacement method [36]. Base saturation, Exchangeable Sodium percentage and Sodium Adsorption Ratio were calculated as outlined in the Harmonized World Soil Database (version 1.1) as follows:

$\%BS = \text{Exchangeable} \frac{\text{Bases}}{\text{CEC}} \times 100$……………………………Equation 1

Where BS=Base saturation.

CEC= Cation Exchange Capacity

Where ESP=Exchangeable Sodium Percentage.

$ESP = Na \times \frac{100}{CEC}$…………………………………………….Equation 2

$SAR = \frac{\text{Na}}{\sqrt{(\text{Ca}+\text{Mg})/2}}$…………………………………………….Equation 3

2.8. Data Analysis

Data obtained from the physicochemical measurements were statistically analyzed using SPSS Version 20 computer package using analysis of variance (ANOVA) for randomized complete block design (RCBD). Significant treatment means were further tested using Fisher's Least Significant Difference (F–LSD) as described [37]. Differences in treatment means were judged significant at 5% level of probability.

3. RESULTS AND DISCUSSION

3.1. Soil physical properties

Table 1: Effect of Gmelina and Gliricidia on physical properties of the soil

Treatments	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	Tx.C	Bulk density (gcm^{-3})	Total porosity (%)	GMC (%)
GmPA	530.7	310.0	159.3	Loam	1.54	42	26.8
GmFA	350.7	476.6	172.7	Loam	1.61	39	23.2
GlPA	637.3	270.0	92.7	S.Loam	1.55	42	22.0
GlFA	474.0	383.3	139.3	Loam	1.68	38	25.6
$FLSD_{(0.05)}$	6.78	6.58	5.87		0.55	NS	0.68

GmPA = Gmelina Plantation Area, GmFA= Gmelina Free Area, GlPA= Gliricidia Plantation Area, GlFA= Gliricidia Free Area, GMC= Gravimetric Moisture Content, Tx.C = Textural Class, NS= Not significant, S.Loam = Sandy Loam

Table 1 shows the effect of tree plantations: Gmelina and Gliricidia on soil physical properties. The results revealed that sand content of the soil under Gmelina was significantly (P<0.05) higher than that under Gmelina free. Moreso, the sand composition of the soil at Gliricidia was significantly (P<0.05) higher than that under Gliricidia free area. Various authors have previously reported dominance of sand fraction in soils of southeastern Nigeria [38-40]. The percentage silt as recorded in the Gmelina area was significantly (P<0.05) lower than that under Gmelina free area. Silt composition of the soil at Gliricidia plantation significantly (P<0.05) lower than the area under Gliricidia free. Clay concentration was significantly (p<0.05) lower under Gmelina and Gliricidia plantation than that of the areas under Gmelina free and Gliricidai free (control).

Reason for higher value of sand at Gmelina and Gliricidia plantation than that of Gmelina and Gliricidia free soil could not be ascertained in this study. However, it is known that under plantation, leaching activities are higher, bulk density lower and total porosity is higher, soil materials of which may lead to downward movement of material like silt and clay. This study further revealed that the Gmelina and the Gliricidia plantations did not have any effect on the texture of the soil. This assertion is supported by the work which stated that particle size distribution is a permanent component of the soil and does not change much with time [41].

Bulk density of the soil at the Gmelina and Gliricidia plantations were significantly (P<0.05) lower than that of the soil under Gmelina and Gliricidia free area (Table 1). The results further revealed that bulk density was higher in Gmelina and Gliricidia free areas. High bulk density recorded in the plantation free area is attributed to compaction due to the activities of human traffic and movement within the plantation areas. Previously study reported a similar finding in a study in southeastern Nigeria [39].

The open pore space in the Gmelina and Gliricidia free areas has allowed rain drop impact to compact the soil leading to higher bulk density. Lower bulk density recorded in Gmelina and Gliricidia plantation is as a result of litter fall accompanied by decomposition leading to higher organic matter which in turn reduced bulk density, activities of roots and root decays [42]. He stated that the contribution of roots system to soil organic matter pool as a result of decomposition and decay and their cumulative annual input to the soil organic pool can be quite high in comparison to above-ground litter.

Moisture content in Gliricidia plantation was significantly (P<0.05) lower than that of the Gliricidia free area. Higher moisture content was recorded at Gmelina plantation area and this could be linked to higher litter fall, high decomposition and accumulation over previous years leading to build up of biomass which help in soil moisture retention, the tree branches and leaves also aided in shading the soil surface to reduce evaporation in the Gmelina and Gliricidia plantations. In addition, it might also be linked to differences in decomposition rate between Gliricidia plantation and Gliricidia free area attributed to differences in litter accumulation.

According to a study, decrease in total nitrogen content (as well as increasing lignin content of biomass) is associated with decrease in decomposition rates, thus decomposition rates are very high for relatively N-rich leaf or bark litter in comparison with rather lignin-rich wood [43].

3.2. Soil chemical properties

Effect of Gmelina and Giricidia plantations on chemical properties of the soil is presented in Table 2. The results however indicate that there was no significant difference (P>0.05) in pH levels of the soil in Gmelina and Gliricidia plantations. Soils in Gmelina plantations area were lower in pH and higher in Gmelina free area, while soils in Gliricidia plantations showed higher pH when compared to Gliricidia free area. Our finding is in line with previous study by who stated that there was no significant difference (P>0.05) in pH levels of the soil samples from the two-plantation species (Gmelina and Nauclea) [44]. However, the pH values obtained in the plantations did not fall within suitable pH range (6.47and 7.47) for effective growth and development of the species [44]. Nevertheless, the pH range in the present study is similar to the range of pH values of 3.8 – 4.5 and 4.1 – 5.6 respectively in studies of different land uses in southeastern Nigeria [40, 45].

Table 2: Influence of Tree plantation on Chemical Properties of the Soil

Treatments	pH (H_2O)	OM (%)	N (%)	P (m gkg^{-1})	CEC ($Cmolkg^{-1}$)
GmPA	4.88	2.352	0.115	26.17	10.19
GmFA	4.90	1.580	0.092	19.00	11.35
GlPA	5.08	2.690	0.142	34.37	11.64
GlFA	4.65	2.118	0.116	26.82	9.54
$FLSD_{(0.05)}$	NS	0.71	NS	NS	1.12

GmPA = Gmelina Plantation Area, GmFA= Gmelina Free Area, GlPA= Gliricidia Plantation Area, GlFA= Gliricidia Free Area, OM = Organic matter, N=Nitrogen, P= Phosphorus, NS= Not Significant, CEC = Cation exchange capacity.

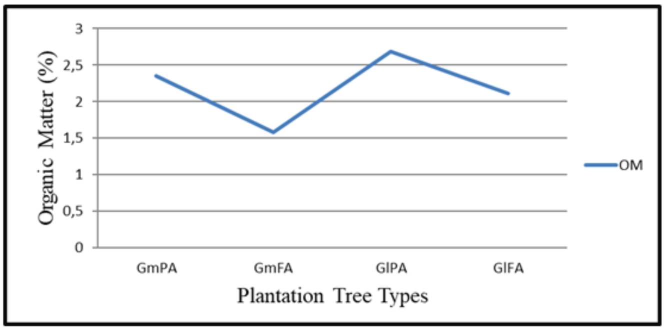

Figure 4: Organic Matter Trend

Effect of Gmelina and Gliricidia plantations on organic matter content of the soil shows significant difference (P<0.05), thus higher organic matter content was recorded in both Gmelina and Gliricidia plantations when compared to Gmelina and Gliricidia free areas (Figure 4). Increment in organic matter content of soils supporting Gmelina and Gliricidia is attributed to the leaves of Gmelina and Gliricidia which are virtually completely shed annually [46]. More so, the relatively fast decomposition rate of Gmelina leaves indicates the importance of the foliage in nutrient cycling.

Our findings further showed that there was no significant difference (P>0.05) in the concentration of nitrogen and phosphorus. Nitrogen and phosphorus content showed general increased values in both Gmelina and Gliricidia plantations when compared to free Gmelina and Gliricidia areas. The overall increase in nitrogen and phosphorus could be attributed to accumulation of litters in Gmelina and Gliricidia plantations which easily decomposes to add more nutrients to the soil. Significant improvement in soil nitrogen under Gmelina plantations in Nigeria, without supplementary addition of nutrient in a single rotation has been reported [47]. Hence, Gmelina seems not to deplete the nutrient base of its site. Secondly, the solubility of P is pH dependent: naturally low in solubility in the soil especially in acidic/highly weathered soils of southeastern Nigeria because phosphate adsorption generally increases as pH decreases. This is also because P fixation inclines to be more pronounced in acid soils and ease of phosphorus release tends to be lowest in soils with higher clay content made similar observation, that understory and litter cover play a significant role as sink for cation in plantations to boost chemical properties of the soil [48-50]. Cation exchange capacity (CEC) was found to be lower in the two plantations though with higher values in plantation free areas (control). Low content of cation exchange capacity in Gmelina and Gliricidia plantations implies that the soil has a relatively lower resistance to change in soil chemistry due to human interference by exposing the plantation to leaching and erosion [53].

3.3. Chemical exchangeable Bases

Results on effect of Gmelina and Gliricidia plantations on exchangeable chemical bases of the soil is presented in Table 3. The overall results of exchangeable bases of the soil indicate that Ca, Mg, BS, ESP and SAR differs significantly (P<0.05). However, K and Na did not differ significantly (P>0.05) from the influence of Gmelina and Gliricidia plantations.

Table 3: Influence of Tree Plantation on Chemical Exchangeable Properties of the Soil

Treatments	Ca ($Cmolkg^{-1}$)	Mg ($Cmolkg^{-1}$)	K ($Cmolkg^{-1}$)	Na ($Cmolkg^{-1}$)	BS (%)	ESP (%)	SAR
GmPA	5.93	2.40	0.112	0.090	84	0.88	22.68
GmFA	6.47	3.20	0.121	0.091	87	0.80	24.16
GlPA	7.07	3.20	0.169	0.078	90	0.67	29.05
GlFA	5.07	2.47	0.155	0.086	82	0.90	22.58
$FLSD_{(0.05)}$	1.57	0.66	NS	NS	3.16	0.06	2.18

GmPA = Gmelina Plantation Area, GmFA= Gmelina Free Area, GlPA= Gliricidia Plantation Area, GlFA= Gliricidia Free Area, BS= Base Saturation, ESP= Exchangeable Sodium Percentage, SAR= Sodium Adsorption Ratio, NS= Not Significant

Results indicates that potassium, calcium, magnesium and sodium were lower in Gmelina plantation compared to the Gmelina free areas except exchangeable acidity which was higher in Gmelina plantation compared to Gmelina free area. This could possibly be as a result of severe leaching process in the Gmelina plantation when compared to Gmelina free area, since majority of Gmelina plantation soils were located in area of higher elevation than Gmelina plantation free areas (Figure 3). This scenario thus has the capacity to reduce the organic matter content in Gmelina plantation. Observably, higher values for potassium, sodium, calcium and magnesium was also recorded in Gliricidia plantation when compared to Gliricidia free areas. This is as a result of less leaching process in Gliricidia plantation. Low values of Ca, Mg, Na and K in most Nigerian Gmelina soils have been reported by various authors and this is as a result of leaching of nutrients due to soil erosion accelerated by high rainfall in the region [20, 51,52].) Base saturation (BS) were found to be lower in the two plantations but was higher in plantation free areas (control). Exchangeable sodium percentage (ESP) is a property of the soil that is used to indicate levels of sodium in soils [54].

Sodium adsorption ratio (SAR) differs significantly ($P<0.05$), as prescribed according to the rating from Harmonized World Database [54]. The result implies that Gmelina plantation, Gmelina free area and Gliricidia free area were high (15%-25%) in SAP except for Gliricidia plantation where SAP was observed to be very high (>25). SAR is used to indicate levels of sodium hazards for crops and its agronomic relevant limits [54]. Therefore, top soil from these soil plantations cannot be recommended for growing crop as it's beyond safe limit to be use in soil amendment or solving soil infertility problem.

4. CONCLUSION

Incorporation of accumulated litter biomass from leaves fall in the areas with plantation (Gmelina and Gliricidia) helped in boosting the organic matter content in the top soil therefore, ensuring conservation of soil moisture and enhanced nutrient release. The exotic tree species used in this study were leguminous tree as reflected in the study and thus, has boosted the nitrogen and soil organic matter content as well as other chemical and exchangeable bases through bacteria that lives in the nodules of their roots. The integration of trees, especially leguminous nitrogen – fixing trees into agricultural farming systems can make major contribution to the restoration and maintenance of soil fertility through organic matter and N-inputs. The ability to fix atmospheric nitrogen allows these leguminous trees to grow well in N-deficient soils as observed in our current study.

Their nodulated roots and above – ground residues are also valuable sources for building levels of soil organic nitrogen. Following the observation and results obtained in this study, it is therefore necessary to state that Gmelina and Gliricidia plantation have the capacity to protect the soil, restore degraded soil, conserve soil moisture and ensure nutrient cycling through the soil plant system., Furthermore, Gmelina and Gliricidia plantation improved organic matter and humus which enhanced the activities of micro-organism which act on the humus to release water and nutrient which could be absorb directly by plant. Due to huge capital requirement, only the Government is investing in establishment of tree plantation in Abakaliki, Nigeria. However, active participation of rural farmers and other stakeholders could help in reducing deforestation and promoting afforestation in view of ensuring provision of ecosystem services and environmental sustainability.

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