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Amelioration Effect of Three Agroforestry Trees on Soil Physico-Chemical Properties in Wukari Taraba State, Nigeria

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Abstract: Improvement in soil fertility under Agroforestry occurs mainly through the addition of plant biomass (leaf litter). This research was conducted on an agroforestry farm adjacent to the Sonkpa forest reserve in Wukari Local Government Area. Soil samples were collected under three agroforestry trees (*Daniella oliveri*, *Parkia biglobosa, Vitellaria paradoxa*, and agricultural soil as a control). The soil samples were collected at depths of 0–30 cm and replicated three times for the soils supporting each species using a soil Auger and core sampler. Soil samples collected were analysed for pH, organic carbon, Total Nitrogen, Available Phosphorus, exchangeable acidity, exchangeable hydrogen, aluminium, calcium, Magnesium, and particle size distribution. The data were subjected to an analysis of Variance (ANOVA) to test for a significant difference in the physico-chemical properties of the soils. The pH result showed near-neutral to alkaline conditions, which range from 7.3 to 7.6. Organic carbon ranged from 2.3–2.9, available phosphorus ranged from 2.1–4.1, exchangeable hydrogen was less than 7.0, which showed the alkalinity of the soil, magnesium ranged from 0.7–1.1, aluminium ranged from 0-0.10, calcium concentration ranged from 2.2–1.87, The study of soil physico-chemical characteristics under the three tree species and control indicated that soil conditions could be influenced by agroforestry. The study, therefore, recommends farmers embrace agroforestry for improved soil physico-chemical properties.
Keywords: Agroforestry, plant biomass, physico- chemical, organic carbon.

INTRODUCTION

Most food crops in Nigeria are produced by subsistence farmers, who over the years have practised burn and shifting cultivation to sustain yield even at a low level (Ureigho *et al*., 2020). The increasing human population has led to intensive cultivation without adequately replenishing soil nutrients. The result has been a decline in crop yields and the depletion of the source base. The soil becomes fragile and quickly loses organic matter and nutrients when exposed to harsh conditions or intensive cultivation. Soil is the dominant ecosystem that serves as the storage of transformed organic substances, mainly recycled soil and organic carbon (Gruhn *et al.*, 2000). Improvement in soil fertility under agroforestry systems occurs mainly through the addition of plant biomass. The importance of tree-based land use systems in restoring soil fertility and improving the economies of farmers with small land holdings has been realised during the last two decades (Franzel, 1999).

Soil is the outer soft layer of the earth, formed by a different process generally called soil-forming forces. The soil formation process varied from place to place depending on the environment. Even with the increasing need for forest plantations and their importance to human well-being, the implications of forest plantations on soil physiochemical properties remain an important point to note in environmental studies (Van Breemen and Buurman, 2002; Anthony & Essien, 2018). Trees accumulate considerable amounts of carbon and nutrients in their biomass, part of which is removed during harvest. Trees have been known to play an important role in soil fertility management through the addition of litter, decaying of roots, nutrient cycling, and biological nitrogen fixation (Sarvade *et al*., 2014). Tree species affect decomposition through direct and indirect effects. Direct effects occur through leaf litter quality, while indirect effects relate to unique effects that the plant species creates in the surrounding environment. Being naturally adapted to local soils and climates, indigenous wild trees often survive environmental stresses better than introduced species, and these constitute important biological resources in the global agro-biodiversity context.

Adedayo and Sobola (2014) have considered agroforestry systems as viable alternatives to degradative land use systems such as monoculture and inorganic farming. The difference between

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exotic, native, and agroforestry tree species was mainly explained by the impacts that each tree species may have on soil quality and soil biodiversity (Boreux *et al*., 2016; Essien & Anthony, 2017). Some exotic tree species are said to increase soil acidification and consume high quantities of water and soil nutrients, particularly in monodominant stands (Venuste, 2020; Tesfay *et al.,* 2022; Russell et al., 2007). On the contrary, agroforestry tree species, being mostly leguminous, are appreciated for improving soil fertility through nitrogen fixation, resulting in increased agricultural productivity (Sobola *et al.,* 2015b). Indigenous tree species are recognised to enhance biodiversity, conservation of wild species, and soil quality. Sobola *et al.* (2015) concluded that agroforestry tree species such *as Leucaena leucocephala* and *Gliricidia sepium* can provide a rapid flux of Nitrogen during mineralization and are therefore recommended for agroforestry systems.

Land degradation can be reversed with the help of agroforestry since agroforestry systems have a stabilising or beneficial effect on soil resources. Research (Akintan *et al.,* 2022; Sobola, 2022) has shown that trees can improve soil quality by fixing atmospheric N2, thereby increasing soil nitrogen content. Since organic matter plays an important role in the chemical and physical properties of soils, e.g., improved soil fertility, cation exchange capacity, good soil structure, and soil aggregate stability, among others, it would be of interest to study soils under the system of alley cropping to compare the changes in some soil properties with those of pure wooded stands (woodlots). It is anticipated that this study will provide much-needed quantitative information on the measured soil physical and chemical properties under alley cropping (Agroforestry). Few studies explored the relationships between planted tree species and soil physiochemical parameters, indicating the conditions of soil quality in Taraba State. The current study sought to investigate the effect of Agroforestry trees on soil physiochemical properties in parts of the Guinea Savanna, Wukari Taraba State, and Northeastern Nigeria. This is to help strengthen the current drive towards the much-needed conservation of soil and provide prior and updated information concerning the effects of some forest species on soil properties.

MATERIALS AND METHODS

The Study Area

The study was conducted in Wukari local government area of Taraba State, Nigeria which lies 7.85^0 North latitude, 9.78^0East longitude, and 152 meters above sea level and covers an area of approximately 4,308km$^{2.}$ (Oruonye, 2014). The area is characterized by a tropical climate with distinct wet and dry seasons. It belongs to the guinea savannah agroecology with a sub-humid climate. The relative humidity varies as the season (about 40 % in January and 90 % in July), the area has tropical hot and wet weather with distinct rainy seasons (May-October) and dry seasons (November – April). Annual rainfall ranges from 1100 - 1250 mm. (Okrikata, 2016). It has an average elevation of 189 m and a mean annual temperature is about 26.8^o C indicating the tropical nature of the environment and characterization of the climate area as hot (temperature can reach 40^oC in March) (Oko *et al*., 2014).

Method of Data Collection

The field study was conducted in agroforestry farms adjacent to Sonpka forest reserve, Wukari local government, Taraba State, Nigeria. The study site falls within a Guinea savanna ecological zone with a mean annual rainfall of 1525mm with the highest rain in August and September. Soil samples were collected using a 3cm diameter soil auger, from the four land use types. Data were collected in three agroforestry land use, planted with three different tree species namely: *Danielia olivera, Vitellaria paradoxa*, and *Parkia biglobosa.* The samples were collected 5m away from the tree trunk for each species. Soil samples were collected from three different points under each species at depth of 0-30cm and it was replicated thrice from each land use type. The soil samples were bulked and sieved and a composite sample was taken for laboratory analysis to determine the soil physio-chemical properties.

Soil Analysis

The samples were analyzed for pH (1:2.5 soil to water ratio) using a glass electrode pH meter as described by (Bates,1954), and particle size was determined using the hydrometer method as described by (Bouyoucos, 1951). Available Phosphorus was extracted with 1N NH_4F and 0.5N HCl (Bray and Kurtz, 1945) and measured at the wavelength of 660nm. While the regular Micro-Kjeldahl Method as described by Black (1965) was used for the determination of soil total Nitrogen. Potassium, Sodium, calcium, and Magnesium were determined by a Flame photometer (Amrutkar, 2013). The effective cation exchange capacity (CEC) will be determined by calculating the milliequivalents of H, K, Mg, and Ca per 100g of soil (meq/100g soil), (Steve, 2019). Organic carbon and Organic matter will be calculated using the following formula:

$$OC = \frac{B - T \times F \times 0.39}{W}$$

Where:
B = Blank titre value
T = Sample titre value
F= Strength of Ferrous sulphate
W = Weight of sample.
0.39 = Constant

Determination of Soil Physiochemical Properties

Soil pH

Soil pH was determined electronically with a pH meter. 10 grams of each air-dried sample was weighed into beakers. Which added 200ml of distilled. The suspension was stirred several times over a 30 minutes interval. The pH of the soil was then determined in the medium with a pH meter (Kalray, 1995).

Organic Carbon Content

This was determined using the Walkley-Black method. About 1g of each sample was weighed into a 250ml flask and 10 ml of potassium dichromate (k2cr2o7) was added to a swirl. This was followed by 20 ml of concentrated H2so4. The reagent was mixed vigorously for about 1 minute. After allowing the soil sample mixture to stay for 20 minutes, 40ml of distilled water and 3 drops of O-phena-athroline indicator were added. The solution was titrated to a whine-red endpoint with ferros ammonium sulphate (Magdoff *et al*., 1996).

Organic matter content

The organic matter content (%) of the soil sample was obtained by multiplying the percentage of carbon by 1.724 (Magdoff *et al*., 1996). Thus, %organic matter= %organic carbon x 1.724

Nitrogen determination

The sample solution was digested in a fume cupboard using the semi-micro Kjedahl method with selenium catalyst (Bremmer, 1996). The digested sample was distilled after the addition of 40% of sodium hydroxide (NaOH) and the ammonia released was determined by simple acid-base titration method.

Phosphorus determination

Molybdenum blue method was used to determine the availability of phosphorus in the samples (Debosz *et al*., 2002).

Mg/kgp= *RxVxD/wt* (Debosz *et al*., 2002).
Where;
R= reading from the graph
V= volume of extraction
D= dilution factor
Wt= weight of soil sample
Calcium (Ca2+) and Magnesium (Mg2+) determination
The Ca2+ and Mg2+ content in the sample
soil was also determined by employing the EDTA titration method (Ibitoye, 2002).
Calcium mMol/100g= T1 x M (EDTA) X v1/v2 x 100/w
Magnesium mMol/100g= (T-Tm) x M (EDTA) X v1/v2 x 100/w
Where;

T1 = titer value for each value alone
Tm = titre value for Magnesium
v1 = Volume of extracted solution
v2 = Volume of extracted sample used in titration
W = weight of sample used for extraction Mg2+ = (Ca2+ + mg2+) – Ca2+

Determination of cation exchange Capacity

1. Dissolved 136g sodium acetate tri-hydrate (CHOONa.3H2O) in about 950ml DI water, mix well, and let the mixture cool. Adjust pH 8.2 by adding more acetic acid or sodium hydroxide**,** and bring to I-L volume with DI water.
2. Ammonium acetate (NH4OAc) 1.0M: Dissolve 77.09g of ammonium acetate in distilled water and dilute to about 900 ml. Adjust the pH to 7.0 with dilute ammonium hydroxide or acetic acid as required, and make the volume up to 1 liter.

Determination of Exchange Acidity in soil

5g of air-dried soil was weighed into a 250ml flask, and added with 100ml extracting solution. The solution was shaken for one hour and filtered into a 100ml volumetric flask and made it up to mark 1MKCl.

Determination of H+ and Al (Exchange acidity)

Pipette 25ml of KCL extract in 250ml flask (use 50ml if PH of soil is above 5.0), was added to distilled water. 5 drops of phenolphthalein indicator were added, and the solution was titrated with 0.01 NaOH to a first permanent pink end-point with alternate stirring and standing. Few more drops of indicator to replace what is adsorbed by the precipitate of Al (OH)3. Blank titration 25ml of 2M KCL was carried out.

Determination of Potassium

2.5 grams of fertilizer was placed in a 250-mL tall beaker.150 ml of distilled water was added, covered with a watch glass, and boiled for 30 minutes. Cool, diluted to volume with water, and mixed thoroughly, filter through a dried filter, and allowed it to stand overnight. For samples containing less than 20% K2O, transferred of a 25-mL aliquot to a 100ml flask, diluted to volume, and shaken thoroughly. For samples containing more than 20% K2O, a smaller aliquot was used.

Determination of Sodium

250ml beaker was carefully opened. 150ml distilled water added and gently swirl the contents until dissolved. The solution was poured into a 200ml volumetric flask and rinsed out the beaker with small amounts of distilled water, adding the washings to the flask. Finally, make up the flask to exactly 200ml and mix thoroughly.

Data Analysis

The Data generated were subjected to Analysis of variance (ANOVA) for an experiment in a completely randomized design (CRD) using the GENSTAT package to test for the significant differences in soil physiochemical characteristics between the three different tree species (*Danielia olivera*, *Vitellaria paradoxa*, *Parkia biglobosa)* and control. The means were separated using Fisher's least significant difference (LSD).

RESULTS AND DISCUSSION

Physiochemical Properties of An Agricultural Farm in the Study Location Soil

The general physico-chemical properties of soil at 0 -30cm of the farmland is presented in **Table 1.** The textural class was Sandy clay loam (USDA). The PH of the soil (Ph-7.37) was slightly alkaline according to the rating of Landan (1991). The organic carbon (2.60 g kg^{-1}) and total N (0.29 g kg^{-1}) were low according to London 1991 rating, However Chude *et al.*, (2011) gave a *high classification for 0.16 -0.20 g kg^{-1}* total nitrogen in the soil. **The** Available Phosphorus (4.10 mg kg^{-1}), and cation exchange capacity (5.2 cmol/kg) with an exchangeable acidity H^+ and $AL^{3+}$of 0.30 were low according to London

(19991 ratings. The calcium and magnesium values of the study area were low (2.21 cmol kg^{-1}) and (0.75 cmol kg^{-1}) respectively. Indicating possible deficiency according to Chude *et al* 2011

Table 1: Soil physical and chemical properties

Parameters	**Values**	**Rating by Landan 1991 and Chude *et al.,* (2011)**	**Remark**
pH (H_2O 2:1)	7.37	7.3 – 7.8	Slightly Alkaline
Org. Carbon g kg^{-1}	2.60	< 10	therefore it's low
Total N g kg^{-1}	0.29	0.21 – 0.24	Very high
Avail P (mg kg^{-1})	4.10	**≥3.2 ≤7.0**	**Low**
Exchangeable Acidity	0.30		Low
Exchangeable H	0.3		Low
Aluminium (mg kg^{-1})	0.1	< 1	Indication of Alkaline soil
Calcium (cmol kg^{-1})	2.21	10 -100	Low (possible deficiency
Magnesium (cmol kg^{-1})	0.75	**≥0.3 ≤1.0**	Low
Particle Size Distribution (USDA)			
%Sand	83		
%Silt	15		
%Clay	29		
Textural Class	Sandy clay loam		

Soil Chemical Properties under Three Agroforestry Tree Species

Table 2: shows the results of the chemical characteristics of soil under agroforestry tree species. the highest pH value for the soil sample ranged (7.37 -7.60) with the highest obtained from the soil sample under *the vitellaria paradoxa* plot (pH - 7.60) and the lowest from the control (7.37). However, the result of the analysis of variance revealed that there was no significant difference ($p \geq 0.05$) in the pH value under the different agroforestry trees.

The organic carbon content of the soils ranged (2.60 -6.64 g kg^{-1}) with the highest in soil under Daniellia *oliveri* (6.64 g kg^{-1}) while the least organic carbon was obtained from *Parkia biglobosa plot* (2.34 g kg^{-1}). The different species show significant differences ($P \leq 0.05$). means were obtained for organic carbon from the soil samples under Daniellia *oliveri* giving higher organic carbon (6.64 g kg^{-1}) and the least organic carbon was obtained from *Parkia biglobosa plot* (2.34 g kg^{-1}). The soil available phosphorus was significantly different ($p \leq 0.05$) with the highest value obtained from the control (4.10 g kg^{-1}) followed by *Daniellia oliveri* (3.35 g kg^{-1}) and lowest in P*arkia biglobosa* (2.10 g kg^{-1}).

Table 2: Influence of three tree species on the concentration of organic carbon, total nitrogen, and available phosphorus in the soils

Variables	**pH** (H_2O 2:1)	**Org. Carbon** (g kg^{-1})	**T. Nitrogen** (g kg^{-1})	**Avail. P** (**m**g kg^{-1})
Daniella	7.40^{a}	6.64^{a}	0.74^{a}	3.35a
Vitelleria	7.60^{a}	2.91^{b}	0.32^{b}	2.70^{b}
Parkia	7.54^{a}	2.34^{bc}	0.26^{b}	2.10^{c}
Control	7.37^{a}	2.60^{c}	0.29^{b}	4.10^{d}

P-Value	0.1612	0.0000	0.0021	0.0000
S- error	0.0737	0.0981	0.0634	0.0473

There was no significant difference ($p \geq 0.05$) in exchangeable acidity of soils under the different species *Daniella oliveri* (0.40 cmol kg^{-1}) had higher exchangeable acidity compared with the control (0.30 cmol kg^{-1}). (Table 3) .In the same vein, exchangeable hydrogen was also not significantly different ($p \geq 0.05$) among the different samples as uniform values (0.30 cmol kg^{-1}) were obtained for all the samples. Results for Aluminum were however significant for all the soil samples ($P \leq 0.05$) *Daniella oliveri* (0.10 cmol kg^{-1}) and *Parkia biglobosa* (0.10 cmol kg^{-1}) have the higher value and control (0.00mol kg^{-1}) with the lowest value. The analysis of variance showed a significant difference ($P \leq 0.05$) with a higher value of calcium obtained from soil under *Daniella oliveri* (2.87 cmol kg^{-1}) and the lowest value from control (2.21 cmol kg^{-1}). The result for magnesium was not significant for all the soil samples ($p \geq 0.05$) with a higher value obtained from *Danillia oliveri* (1.12 cmol $kg^{-1)}$ and the lowest value obtained from the control (0.75 cmol kg^{-1}).

Table 3: Influence of Three Tree Species on Concentration of Exchangeable Acidity, Exchangeable Hydrogen, Aluminum, Calcium and Magnesium in The Soils

Variables	Ex. Acidity	Exc. Hydrogen	Aluminium (mg kg^{-1})	Calcium (cmol kg^{-1})	Magnesium (cmol kg^{-1})
Daniella olivera	0.40^{a}	0.30^{a}	0.10^{a}	2.87a	1.12^{a}
Vitelleria paradoxa	0.35a	0.30^{a}	0.05^{a}	2.81^{a}	1.06^{a}
Parkia biglobosa	0.40^{a}	0.30^{a}	0.10^{ab}	2.64a	1.01^{ab}
Control	0.30^{a}	0.30^{a}	0^{b}	2.21^{b}	0.75^{b}
P-Value	0.7887	1.0000	0.0142	0.0043	0.0600
S- error	0.0806	0.0616	0.0185	0.0938	0.0842

DISCUSSION

Apart from climate, soil characteristics are believed to play important roles in the survival and performance of plants. Soil pH in particular can be considered a key variable due to its influence on many other soil properties and processes affecting plant growth. (Gentili *et al.*, 2018). In the present studies, the pH of the soil under the three tree species and the control were slightly alkaline which is optimum for many plant species except those species that prefer acid soils. For such soil, there are possible deficiencies of available phosphorus and some metals e.g. Zinc (Chude *et al*., 2011). The result shows improvement or amendment in soil pH under the agroforestry trees when compared with the control. The organic carbon content of the soils was significantly higher in soil under *Daniella oliveri* (6.64 g kg^{-1}) compared to other soil samples which indicates the potential of the species to sequester carbon at a higher rate.

Soil organic carbon is an important component for the functioning of agroecosystems, and its presence is central to the concept of sustainable maintenance of soil health, therefore a meager change in soil carbon sequestration will have a drastic impact on the global carbon cycle and climate change (Ngatia, 2021). Organic carbon obtained in this study revealed the ability of leave litters to boost the carbon pool of soils this aligns with the report of Sobola *et al.* (2016) who reported that Soil organic matter comprised approximately 50% carbon (C) which when incorporated into the soil, can boost the organic carbon pool of the soils under vegetation cover. The soil available phosphorus was significantly different ($p \leq 0.05$) with the highest value obtained from the control (4.10 g kg^{-1}) followed by *Daniellia oliveri* (3.35 g kg^{-1}) and lowest in *Parkia biglobosa* (2.10 g kg^{-1}). However, based on the soil rating by Landon 1991 the soils are still categorized as low for soils under Daniella oliveri and the control while soil under *Vitellaria paradoxa* and *Parkia biglobosa* the soils were rated very low in available phosphorus.

The low concentration of phosphorus in this study aligns with the soil textural class, Sandy clay loam, Previous research has found that sandy soils are mostly susceptible to phosphorus leaching which could also be attributed to low mineralization in the study area (Brigham, 1998)). However, the addition of organic matter to soil is a sure way to increase Phosphorus availability in soil, by forming phosphate which increases phosphate uptake by the plant, in addition, organic anions can also displace sorbed phosphate. Humus coats aluminium and iron oxides and amorphous minerals (Lloyd *et al.,* · 2001). Generally, the exchangeable acidity in the present study is low for all the soil samples, though *Daniella oliveri* (0.40 cmol kg^{-1}) had the highest exchangeable acidity. Exchangeable acidity is the amount of H+ and Al3+ ions retained on soil colloids after the active acidity has been measured. Soil conditions and numerous soil processes are affected by high exchangeable acidity and low pH. The bioavailability of iron, aluminum, or manganese can be extremely high and may approach lethal levels at lower pH levels in an acidic state, which causes aluminium to fix phosphorus and cause its deficiency in plants. (Soetan, *et al.,* 2010). Although the concentration of aluminium was significantly higher in

($P \leq 0.05$) *Daniella oliveri* (0.10 cmol kg^{-1}) and *Parkia biglobosa* (0.10 cmol kg^{-1}) but generally, the values show very low content in the soil under the various land use type. Aluminium toxicity is a major constraint for crop production in acidic soil, when the soil pH is lower than 5, Al3+ is released into the soil and enters the tip thereby stopping root development (Garvin, & Carver, 2003).; Lahua *et al.,* 2021). This research also shows that magnesium is averagely available in the soil under the different agroforestry species but that of the control is low based on the soil rating by London 1991 Hence it is an indication of soil improvement under the tree species as magnesium is the central core of the chlorophyll molecule in plant tissue. Thus if Mg is deficient, the shortage of chlorophyll results in poor and stunted plant growth. Calcium concentration in this study is equally normal and will contribute to healthy soil structure and stabilization of organic matter which will increase soil water and nutrient holding capacity (Adugna, 2016).

CONCLUSION AND RECOMMENDATION

Soil pH plays a crucial role in plant survival and performance. A slightly alkaline soil pH, as observed in the study, is generally optimal for many plants. Agroforestry trees, *Danielia oliveri, Vitelaria paradoxa, and Parkia biglobosa*, generally exhibited improved soil characteristics compared to the control, indicating their potential to modify soil characteristics positively. This alteration can have implications for plant growth and ecosystem health. The presence of higher organic carbon content in the soil under *Daniella Oliveri* suggests its ability to sequester carbon at a higher rate. Organic matter, such as leaf litter, can contribute to the soil's carbon pool and enhance the soil's organic carbon content. The study suggests that agroforestry trees can positively influence soil pH, organic carbon content, and nutrient availability, which are crucial factors for plant growth and ecosystem sustainability. However, further research is needed to assess the long-term effects of these agroforestry practises on soil health and plant performance.

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