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PHOSPHORUS DISTRIBUTIONS AND FORMS IN SAVANNA SOIL UNDER SELECTED FOREST LAND USES IN NORTHWESTERN, NIGERIA.

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ABSTRACT

In addition to providing a variety of ecosystem services like food production, water management, nutrient cycling, carbon sequestration, and biodiversity protection, soil is an essential natural resource that sustains life on earth. The study assessed phosphorus distributions and forms in savanna soil under selected forest land uses in northwestern, Nigeria. This experiment used a completely randomized design with a 4 x 2 factorial layout. Four land uses and soil samples from two soil depths were included in the variables. Analysis of Variance was used to analyze the data. The findings confirmed that sandy loam was the textural class of the land use categories in the studied locations. The leaves of Moringa oleifera contain the highest nitrogen content (20.00 g kg^{-1}) and low C: N (31.54 g kg^{-1}) among others. The soil pH (6.55), available phosphorus (13.50 mg kg^{-1}), magnesium (0.35 C mol kg^{-1}), potassium (0.09 Cmol kg^{-1}) had significantly ($p < 0.05$) higher values in M. oleifera plantation than other land use. The amount of soil physical and chemical properties increased with the soil depth of 0-30 cm. The values of the phosphorus (P) forms increased in M. oleifera with the significantly ($p < 0.05$) higher values (7.37 mg kg^{-1}) in calcium phosphorus (Ca-P), (4.75 mg kg^{-1}) in iron phosphorus (Fe-P mg kg^{-1}) and (13.55 mg kg^{-1}) in available phosphorus (Av-P). In conclusion, M. oleifera plantation provides an adequate soil phosphorus form that is sustainable to improve soil quality and fertility.

Keywords: Phosphorus distributions, forms, savanna soil, forest land use, soil fertility

INTRODUCTION

Soil is a vital and critical natural resource that supports life on earth (Bhattacharyya *et al.*, 2015). It provides various ecosystem services, such as food production, water regulation, nutrient cycling, carbon sequestration, and biodiversity conservation (Daba and Dejene, 2018). However, anthropogenic activity and environmental changes can also deteriorate and deplete soil, which is a limited and non-renewable resource. In order to guarantee sustainable land management and food security, it is crucial to evaluate the fertility and quality of the soil (Mucheru-Muna and Ngetich, 2017).Hence, assessing of the distribution of soil phosphorus and forms in a degraded alfisols is essential. Many types of phosphorus (P) are found in the environment and can be assimilated; as a result, they have long been utilized as fertilizers (Makttoof *et al.*, 2020). Plant growth requires phosphorus, and cropping systems' viability depends on maintaining a sufficient level of soil phosphorus by the use of inorganic and/or organic phosphorus.

Both organic and inorganic forms of phosphorus can be found in soil. Until the organic substance is broken down by microbes and transformed into inorganic forms, plants are comparatively unable to absorb organic forms of phosphorus. More than half of the phosphorus in soil is in the organic form, which is present in humus and plant waste (Suhana *et al.*, 2019). In addition to its ability to increase yield, continual fertilization of P may have long-term effects that alter the availability and percentages of soil P (Lai *et al.*, 2003). The varying activities of different ions in the soil, pH, age, drainage, fertilizer techniques, and mineralogical character, climate, and management practices all affect the distribution of different forms of inorganic phosphorus in soils (Rowe *et al.*, 2016). Generally speaking, though, 80-90% of the soil P (residual P) is adsorbed on the soil elements and accumulates as soil P capital, while 10-20% of the P applied is accessible for crop absorption in the year of application.

There are two primary forms of inorganic phosphorus, also referred to as orthophosphate, found in soil: metal 7 phosphates, in which the phosphate anion (HPO$_4^{2-}$, H$_2$PO$_4^{1-}$, or PO^{4-}) is joined to a metal cation, such as Al^{3+}, Fe^{3+}and $^{2+}$, Mg^{2+}, or Ca^{2+}; and oxide-phosphate complexes, such as a clay edge-phosphate complex (Sposito, 2016). Furthermore, phosphorus is gaining more attention as a key soil fertility resource as a result of the sharp rise in the world's population and the resulting demand for agricultural production (Cordell *et al.*, 2009; Gilbert, 2009). Due to the comparatively high quantity that plants need, P is categorized as an essential and macronutrient in plant nutrition (Brady and Weil, 2016). It has a significant impact on fruiting, seed production, early growth and development stimulation, and energy transfer (Bi *et al.*, 2013; Ali *et al.*, 2014).

The degree to which P is retained in the soil depends on a number of crucial elements. According to Zhou *et al.* (2019), these variables include the soil's pH, clay concentration, and organic matter content. Different chemical types of soil P, such as organic and inorganic, have different distributions and behavioral patterns within the soil. The solubility product of the various phosphates, parent materials, cations present, soil pH, and weathering level may all have an impact on this (Osodeke and Ubah, 2005; Rowe *et al.*, 2016).

MATERIALS AND METHODS

Study Area

Since there are several different types of plantations in the area, this study was conducted at Batagarawa, which is in the Local Government of Katsina State, Nigeria. Based on the 2006 census, Batagarawa LGA's estimated population was 184,575. Its total land area is 433 km^2, and its average annual temperature is 35^0 C. The majority of the population works in agriculture. Dabaibayawa, which has latitude 12°54'17.81" N and longitude 7°36'11.84" E, is situated in the center of Batagarawa. The four land use types chosen within Batagarawa Local Government were plantations of *Moringa oleifera* (Lam.), *Senna siemea* (Lam.), *Eucalyptus camaldulensis* (Dehnhardts), and *Mangifera indica* (Linn.). Table 1 shows the coordinates of these plantations. Soil samples were taken in sterile bags at two depths (0-30 cm and 30-60 cm) from four locations inside each plantation.

Table 1: Description of sampled locations

S/N	Location	Coordinates	Land use
1	Autawa	N 12^0 51′ 51″, E 7^0 35′ 00″	Moringa plantation
2	Dabaibayawa	N 12^0 51′ 33″, E 7^0 34′ 53″	Mango plantation
3	Tashen kanya	N 12^0 50′ 40″, E 7^0 34′ 21″	Senna plantation
4	Tsanni	N 12^0 48′ 30″, E 7^0 33′ 29″	Eucalyptus plantation

Methods of Sampling and Data Collection

The four distinct land uses include; *Moringa oleifera, Senna siamea, Mangifera indica,* and *Eucalyptus camaldulensis* that constituted factor 1 of the 4x2 factorial experiments, which was set up in a Randomized Complete Block Design (RCBD). Soil samples were taken from two soil depths: 0-30 cm and 30-60 cm. To create two composite samples per location, three sub-samples were bulked depth by depth. These samples were then repeated three times, for a total of 28 experimental units. The finest fractions were prepared for laboratory analysis after soil samples were allowed to air dry before being sieved through a 2 mm screen.

Prior to being transported to the laboratory, the soil samples that were collected were promptly placed in polyethylene plastic bags. The soil samples were sieved through a 2 mm diameter sieve after being allowed to air dry at ambient temperature to eliminate any remaining moisture. Bechman's pH meter was used to measure the soil samples' pH in water with a soil-to-water ratio of 1:2.5 (Thomas, 1996). The hydrometer method (Bouyoucos, 1962) was used to determine the soils' particle size distributions. Using the dichromate wet oxidation method, organic carbon was determined according to Walkley and Black's (1934) protocol (Nelson and Sommers, 1996).

Exchangeable bases from the soil were extracted using 1N ammonium acetate (NH_4OAc) at a pH of 7.00. Titration was used to assess the extracts' Ca and Mg content, while a flame photometer was used to determine the extracts' Na and K content (Jackson, 1958). As first proposed by Dean (1938), Chang and Jackson (1957) updated the method of successive extraction using acid and alkaline reagents to characterize the various forms of inorganic phosphorus in soils. Chang and Jackson originally recommended the use of acid and alkaline reagents for extraction (Chang and Jackson 1957; Tiyapongpattana *et al.,* 2004). The phosphorus concentration in the different extracts was ascertained using the phosphomolybdate method (Murphy and Riley, 1962). These procedures are revisions and improvements of the sequence. The dichromate wet oxidation method was used by Walkley and Black (1934) to measure the phosphorus content of soil (Nelson and Somers, 1996).

Data Analysis

The Statistical Analysis System (SAS, 2015) software programme was used to analyze the data using Analysis of Variance (ANOVA). Significant treatment means were separated using the Fisher's Least Significance Difference (F-LSD; $P < 0.05$).

RESULTS

Chemical Composition of Leaves of Trees of the Selected Land use

The chemical compositions of leaves from the trees of the selected land use (i.e., Eucalyptus, Mango, Moringa, and Senna) showed that ***M. oleifera*** contained more nitrogen (20.00 g kg^{-1}), followed by *S. siamea* (18.00 g kg^{-1}) and less in *E. camaldulensis* (14.00 g kg^{-1}), leading to a lower C: N ratio (31.54) followed by *S. siamea* (34.36) and higher in C: N ratio (45.06) in *E. camaldulensis.* Organic carbon was high in *M. indica* (717.00 g kg^{-1}), followed by *E. camaldulensis* (630.80 g kg^{-1}) and ***M. oleifera*** (630.80 g kg^{-1}) and low in *S. Siamea* (618.50 g kg^{-1}). Acid detergent fibre (ADF), lignin, polyphenol, and cellulose (93.00 g kg^{-1}, 37.50 g kg^{-1}, 21.60 g kg$^{-1,}$ and 56.40 g kg^{-1}) were low in *M. oleifera* plantation; meanwhile, acid detergent fibre (A.D.F.), lignin, polyphenol, and cellulose (256.60 g kg^{-1}, 97.60 g kg^{-1}, 28.20 g kg$^{-1,}$ and 169.00 g kg^{-1}) were high in *M. indica* plantation (Table 2).

Table 2: The chemical composition of the land uses leafy biomass of the study area

Land use	Total nitrogen (g kg^{-1})	Total organic carbon (g kg^{-1})	C: N	Acid Detergent Fibre (g kg^{-1})	Lignin (g kg^{-1})	Polyphenol (g kg^{-1})	Cellulose (g kg^{-1})
Eucalyptus	14.00^{c}	630.80^{b}	45.06^{a}	205.30^{b}	92.60^{b}	20.05^{c}	112.70^{b}
Mango	17.00^{bc}	717.00^{a}	42.18^{b}	256.60^{a}	97.60^{a}	28.20^{a}	169.00^{a}
Moringa	20.00^{a}	630.80^{b}	31.54^{d}	93.90^{d}	37.50^{d}	21.60^{bc}	56.40^{c}
Senna	18.00^{b}	618.50^{c}	34.36^{c}	189.00^{c}	76.30^{c}	24.50^{b}	112.70^{b}

Means followed by the same letters within the same column and treatment are not significantly different at a 5% probability level using the Least Significant Difference (LSD).

Selected Soil Properties of the Experimental Locations

Table 2 presents the soil's physical and chemical properties in the soil on each site before the experiment. Standard procedure determined the study determined the analysis. The results showed that silt (474.60 g kg^{-1}), electrical conductivity (0.03 dS m^{-1}), total nitrogen (5.70 g kg^{-1}), total organic carbon (14.00 g/kg), sodium (0.002 C mol kg^{-1}), magnesium (0.34 C mol kg^{-1}) had significantly higher values in *E. camaldulensis* plantation among others. In mango plantation, soil properties of sand (460.00 g kg^{-1}), silt (482.50 g kg^{-1}), electrical conductivity (0.03 dS m^{-1}), sodium (0.002 C mol kg^{-1}), calcium (2.49 C mol kg^{-1}) and magnesium (0.34 C mol kg^{-1}) experienced higher significant difference among others. Furthermore, clay (105.00 C mol kg^{-1}), pH (6.55), available phosphorus (13.50 mg kg^{-1}), magnesium (0.35 C mol kg^{-1}), and potassium (0.09 C mol kg^{-1}) had significantly higher values among other soil properties in *M. oleifera* plantation. Sodium (0.002 C mol kg^{-1}) and magnesium (0.33 C mol kg^{-1}) had substantially higher values in *S. siamea* plantations.

However, the results were comparable, where clay (460.00 g kg^{-1}) only had a considerably higher value in *the M. indica* plantation. Silt (474.60 g kg^{-1}) and (482.50 g kg^{-1}) had appreciably higher values in *E. camaldulensis* and *M. indica* plantations. Clay (105.00 g kg^{-1}) was only higher in *M. indica* plantations. Electrical conductivity (0.03 dS m^{-1} and 0.03 dS m^{-1}) was higher in *E. camaldulensis* and *M. indica* plantations. pH (6.55) was higher in *M. indica* plantation, total nitrogen (5.90 g kg^{-1}) and total organic carbon (14.00 g kg^{-1}) were higher in *E. camaldulensis* plantation, available phosphorus (13.50 mg kg^{-1}) was higher in *M. oleifera* plantation, sodium (0.002 C mol kg^{-1}, 0.002 C mol kg^{-1} and 0.002 C mol kg^{-1}) was higher in *E. camaldulensis, M. indica* and *S. siamea* plantations respectively. Meanwhile, calcium (2.49 C mol kg^{-1}) was more in *M. indica* plantations. Magnesium (0.34 C mol kg^{-1}, 0.34 C mol kg^{-1}, 0.35 C mol kg^{-1}, and 0.33 C mol kg^{-1}) had consistently higher significant values in *E. camaldulensis, M. indica,* and *S. siamea* plantations. Potassium (0.09 C mol kg^{-1}) was higher and more elevated in *the M. oleifera* plantation (Table 3).

Table 3: Effect of land use on soil physical and chemical properties

Soil properties	Eucalyptus Plantation	Mango Plantation	Moringa Plantation	Senna Plantation
Sand (g kg^{-1})	440.00^{c}±0.71	460.00^{a}±1.16	440.00^{c}±7.58	445.00^{b}±2.15
Silt (g kg^{-1})	474.60^{a}±5.58	482.50^{a}±12.10	455.00^{b}±5.69	470.00^{ab}±3.82
Clay (g kg^{-1})	90.00^{b}±3.85	70.00^{d}±3.83	105.00^{a}±1.96	85.00^{c}±2.22
EC (dS m^{-1})	0.03^{a}±0.00	0.03^{a}±0.01	0.02^{b}±0.03	0.02^{b}±0.05
pH	5.80^{c}±0.04	6.19^{b}±0.07	6.55^{a}±0.06	5.80^{c}±0.03
TN (g kg^{-1})	5.90^{a}±0.06	1.70^{c}±0.02	3.00^{b}±0.04b	1.40^{c}±0.00
TOC (g kg^{-1})	14.00^{a}±0.10	4.50^{c}±0.07	7.00^{b}±0.04b	5.00^{c}±0.03
AP (mg kg^{-1})	7.11^{d}±0.65	10.20^{b}±0.58	13.50^{a}±0.80	8.95^{c}±0.14
Na^+(C mol kg^{-1})	0.002^{a}±0.00	0.002^{a}±0.00	0.001^{c}±0.00	0.002^{a}±0.00
Ca^+(C mol kg^{-1})	1.85^{b}±0.18	2.49^{a}±0.27	1.85^{b}±0.20	1.90^{b}±0.13
Mg^+(C molkg^{-1})	0.34^{a}±0.04	0.34^{a}±0.06	0.35^{a}±0.02	0.33^{a}±0.22
K^+ (C mol kg^{-1})	0.07^{b}±0.01	0.08^{ab}±0.01	0.09^{a}±0.01	0.07^{b}±0.05

EC: Electrical conductivity, TN: total nitrogen, TOC: total organic carbon, AP: available phosphorus, Na: sodium, Ca: calcium, Mg: magnesium, K: potassium. Mean with the same alphabet in the same row are not significantly different.

Soil Physical and Chemical Properties of the Soil at Different Depths

The findings of the physical and chemical characteristics of the soil at various depths show that the properties of silt, clay, electrical conductivity, pH, total nitrogen, organic carbon, available phosphorus, sodium, calcium, and magnesium at 0-30 cm depth did not significantly differ from one another. Sand (450.00 g kg^{-1}), silt (465.00 g kg^{-1}), electrical conductivity (0.02 dS m^{-1}), pH (6.11), and total organic carbon (0.68 g kg^{-1}) were significantly higher than other soil properties. However, results were comparable between 0-30 cm and 30-60 cm depths, where clay (90.00 g kg^{-1}), total nitrogen (0.38 g kg^{-1}), available phosphorus (11.39 mg kg^{-1}), sodium (0.002 C mol kg^{-1}), calcium (2.53 C mol kg^{-1}), magnesium (0.42 C mol kg^{-1}) and potassium (0.08 C mol kg^{-1}) were significantly higher at 0-30 cm than between 30-60 cm. Meanwhile, there was no significant difference in silt, electrical conductivity, pH, and total organic carbon at 0-30 cm and 30-60 cm depths (Table 4).

Table 4: Soil physical and chemical properties of the soil depths in the study area

Soil properties	Depth	
	0-30 cm	30-60 cm
Sand (g kg^{-1})	442.50^{b}±3.87	450.00^{a}±2.64
Silt (g kg^{-1})	476.06^{a}±6.57	465.00^{a}±4.30
Clay (g kg^{-1})	90.00^{a}±3.20	85.00^{b}±4.31
Electrical conductivity (dS m^{-1})	0.03^{a} ±0.00	0.02^{a}±0.00
pH	6.07^{a}±0.00	6.11^{a} ±0.08
Total nitrogen (g kg^{-1})	0.38^{a}±0.00	0.23^{b}±0.03
Total organic carbon (g kg^{-1})	0.85^{a}±0.12	0.68^{a} ±0.08
Available phosphorus (mg kg^{-1})	11.39^{a}±0.70	8.53^{b}±0.55
Sodium (C mol kg^{-1})	0.002^{a}±0.00	0.001^{b}±0.00
Calcium (C mol kg^{-1})	2.53^{a}±0.10	1.52^{b}±0.06
Magnesium (C mol kg^{-1})	0.42^{a}±0.00	0.23^{b}±0.02
Potassium (C mol kg^{-1})	0.08^{a}±0.02	0.07^{b}±0.00

Means followed by the same letters within the same row and treatment are not significantly different at a 5% probability level using the Least Significant Difference (LSD).

Determination of Phosphorus Forms on Landuse

In the *E. camaldulensis* plantation, total P (819.45 mg kg^{-1}) had significantly higher value among other phosphorus forms. *M. indica* plantation had significantly higher value (3.50 mg kg^{-1}) in aluminium phosphorus (Al-P) than other phosphorus forms. In *M. oleifera* plantation, calcium phosphorus (Ca-P) (7.37 mg kg^{-1}), iron phosphorus (Fe-P) (4.75 mg kg^{-1}) and available phosphorus (Av-P) (13.55 mg kg^{-1}) had significantly higher values than other phosphorus forms (Table 5).

Table 5: Effect of landuse on phosphorus forms

P Forms	Total- P	**Ca-P**	**Fe-P**	**Al-P**	**Av-P**
Eucalyptus	819.45^{a}±31.84	4.70^{d}±0.22	3.95^{d}±0.28	2.98^{b}±0.05	7.11^{d}±0.65
Mango	528.04^{d}±44.40	5.00^{c}±0.45	4.25^{c}±0.25	3.50^{a}±0.18	10.23^{b}±0.58
Moringa	790.50^{b}±26.53	7.37^{a}±0.45	4.75^{a}±0.20	2.00^{d}±0.07	13.55^{a}±0.80
Senna	603.11^{c}±16.03	5.30^{b}±0.41	4.50^{b}±0.15	2.10^{c}±0.15	8.95^{c}±0.14

Ca-P: Calcium-Phosphorus, Fe-P: Iron-Phosphorus, Al-P: Aluminium-Phosphorus, Av-P: Available-Phosphorus. Means followed by the same letters within the same column and treatment are not significantly different at a 5% probability level using the Least Significant Difference (LSD).

DISCUSSION

The proportion of soil particle size in sand, silt, and clay is a major soil physical property that determines the soil textural class (Oyelowo, 2014). The textural classes in all the land use types of the study areas were all sandy loam soil. This implies that the land use types do not interrupt the soil structure that may in turn affect the soil properties. *M. oleifera* leaves was having high nitrogen content and lowest C-to-N (C: N) ratio than other leafy biomass, and this implies that it had quick or rapid decomposition of its organic materials and early release of nutrients. The result agrees with *Oyebamiji et al.* (2017); Oladoye *et al.* (2019), who pointed out that plant residue of higher quality, decompose faster with the net mineralization of nitrogen after incorporation into the soil. The breakdown of this green biomass is vital in the nutrient cycle made available for plant use (Oyebamiji *et al.,* 2016; 2018).It was observed that both biotic and abiotic variables, and most significantly, residue quality, regulated the fast break down and nutrient release (Teklay, 2007). Nevertheless, *M. oleifera* also contained less lignin, polyphenol, acid detergent fiber, and cellulose, which allowed its organic materials to release nutrients quickly because they could bind proteins. As a result, they determine the quality of organic materials that soil microbes will break down (Oyebamiji *et al.,* 2017). As a result, the chemical makeup of the plant materials controls breakdown and nutrient release.

In the research area, the pH of the soil was both close to neutral and somewhat acidic. According to research by Oladoye *et al.* (2021), tropical soils are generally acidic, which supported the soil's acidity. Leaching of fundamental elements could possibly be the cause. According to Onyekwelu *et al.* (2006), during a season of high rainfall or in a tropical rainforest, nutrients are quickly leached by heavy precipitation. *M. oleifera* plantation was recorded to have more of available phosphorus, magnesium and potassium, as total nitrogen and organic carbon contents were more in *E. camadulensis* plantation; this could be due to the high litter deposit and abundant release of their mineral content into the soil. This observation was in consonant with Fasina *et al.* (2015) who reported at various studies that mineral nutrients are released to improve soil composition in terms of quality. In all the land uses, especially soil properties of total nitrogen, organic carbon, available phosphorus, sodium, calcium, magnesium and potassium are readily more available within the depth of 0-30 cm. This result agreed with Ali *et al.* (2010) who reported that soil mineral contents decrease down the soil profile, and the tree leaves have significantly contributed to the quality of the soil at that depth as equally observed by (Oyelowo *et al.*, 2019).In general, the deeper the soil (between 0 and 30 cm), the more physical and chemical characteristics there were. Regardless of soil erosion, leaching, and nutrient volatilization, as also noted by Ali *et al.* (2010), the decrease in soil depth of 30-60 cm may be due to the fact that organic nutrients are more easily accessible at the top layer of the soil (0-30 cm) than at the bottom layer (30-60 cm).

The richness of *M. oleifera* in Ca-P, Fe-P and Av-P, *E. camadulensis* in Total-P and *M. indica* plantations was as a result of *M. oleifera* tree for instance which is known to be a nitrogen fixing tree, fixes nitrogen directly into the soil to improve its fertility status (Awopegba *et al.,* 2017)). Additionally, the soil parent materials and soil management techniques may be to blame for the high concentrations of the phosphorus forms in the research sites (Asmare *et al.,* 2015).Although, the high deposition of litter on the surface soil of the plantation also contributed to increase the nutrient status of the soil as also noted by Hu *et al.* (2016) and Oladoye *et al.* (2021).

CONCLUSION

All of the research locations' land use types had sandy loam soil as their textural class. In the research area, the pH of the soil was both close to neutral and somewhat acidic. Compared to other leafy biomass, *M. oleifera* leaves had the lowest C-to-N (C: N) ratio and a high nitrogen concentration. The organic components in *M. oleifera* leaves decomposed quickly, and nutrients were released more quickly as well. The amount of soil physical and chemical properties increased with the soil depth of 0-30 cm. A soil depth of 0-30 cm is considered appropriate for quickly assessing and monitoring soil phosphorus forms. *M. oleifera* plantation provides adequate soil phosphorus forms that is sustainable to improve soil quality and fertility due to its ability to release nutrients rapidly into the soil.

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