Scientia Africana, Vol. 23 (No. 4), October, 2024. Pp 303-316
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

STATUS OF SOILS COLLECTED UNDER SOME AGROFORESTRY TREES

Ogazie, C.A.[1*], Ekeke, C.[1] and Odoemelam, H.O.[2]
[1] Department of Plant Science and Biotechnology, Faculty of Science, University of Port Harcourt, Nigeria
[2] Department of Microbiology, Faculty of Science, University of Port Harcourt, Nigeria
*Corresponding author. Email: chinedum.ogazie@uniport.edu.ng

Received: 12-10-2024
Accepted: 30-10-2024

https://dx.doi.org/10.4314/sa.v23i4.26

Journal Homepage: http://www.scientia-african.uniportjournal.info
Publisher: *Faculty of Science, University of Port Harcourt.*

ABSTRACT

Soil the bed rock for natural provision of macro and micro nutrients for plant growth and development. A soil is considered unhealthy when it can longer supply required nutrients for plant growth due to over use or degradation. To mitigate soil low fertility, agroforestry method of raising trees and crops together makes nutrients available continuously for crop production, through dropping of its parts as litter which decays to add organic matter and nutrients to soil. Soils sampled with soil auger from seven agroforestry trees farm lands namely Gmelina arborea Roxb., Treculia africana Decne., Tectona grandis Linn. f., Pentaclethera macrophylla Benth., Irvingia gabonensis (Aubry-Lecomte ex O'Rorke) Baill., Mangifera indica Linn., Annona muricata Linn. and Fallow farmland as control were evaluated for macro and micro elements using standard laboratory methods and results presented with the highest and smallest values from each parameters evaluated: pH: 5.6, 4.5(Fa and Pm);%N,OC:0.21,0.10(Pm, Fl and Ma),3.40,1.30(Pm and Ig);EC (µS/cm):151.0,88.0(Fl and Tg), P, Mn, Fe, Cu, Zn (mg/Kg): 72.10, 19 .60 (Ta and Ma),111.02, 46.27 (Ta and Tg), 138.47,21.51(Pm and Am),1.53,0.80(Pm and Am), 8.08, 1.86(Ta and Mi); %Sand, Silt, Clay:88,70(Am, Ma and Tg), 16.50, 4.60(Ma and Tg, Am), 13.50,7.50 (Tg and Tg, Pm and Am); Ca, Mg, K, Na, Acidity, Al, ECEC(cmol/Kg)3.43, 0.59 (Ta and Tg),1.00, 0.24(Am and Mi), 0.15,0.07 (Pm, Ma, Ig and Am), 0.40,0.35(Tg, Ma, Ig and Am), 16.90,4.05(Tg and Am), 2.8,1.10(Tg and Am), 21.10,8.70(Tg and Am). We conclude by recommending agroforestry practice as way out of managing and sustaining soil health within the agroecosystems for continuous plant and food crop production as well sustaining the environment.

Keywords: Mineralization; Agroforestry trees; Mineral elements; Soil

INTRODUCTION

Farmers have this insight that the yield of arable crop depends on the status of the soil fertility and when average crop yield from farmland begins to decline, it is an indicationthat the soil can no longer support and supply the required soil nutrients for worthy crop harvest, therefore farmers sort and adopted several farming systems methods to ameliorate soil nutrients status (Hoffmann *et al.*2001; Stewart *et al.*2020) which included shifting cultivation, crop rotation, farm yard manure, inorganic fertilizer from plant residues and lately the application of agroforestry trees and crop combination (Hoffmann *et al.* 2001; Stewart *et al.*2020).

Nigeria is an agrarian nation, made up of different agroecological zones (Adenle *et al.* 2020), hence different farming systems methods were adopted to accommodate the diverse agroecosystems and coupled with different crop types. Agricultural practices adopted before now were shifting cultivation, crop rotation, mixed farming etc., which allowed a farmer to clear, and cultivate a piece of farmland for three to five years and with decline of crop yield, abandon land for a new place allowing the farmland to rest and recover from use and degradation (Fadairo *et al.*2020).

In Northern and Southern Nigeria, the methods of improving the soil status naturally are to some extent similar, however, both zones have some advantages and disadvantages over each other. Southern zone relies on its thick vegetation covers including shrubby and herbaceous plants with its numerous branches, leaves, twigs and dead parts which fall and decay to form organic matter (Mayer *et al.* 2020; Prescott and Vesterdal, 2021) and while in Northern zone, Savanna trees, shrubs and herbaceous plants and dropping from the cattle grazing contribute to organic status of the soil (Kgosikoma *et al.* 2013). Hence the moment the virgin land in each zone are opened up and used leads to soil erosion, degradation and loss of organic matter (AbdelRahman, 2023).

These were some methods put in place for upholding soil fertility owing to the availability of plenty uncultivated land in the forest and savanna zones of Nigeria which allows this long period of rest time before coming back to the farmland. However, population explosion and increase in demand for arable farmland for crop production to feed the teaming population and coupled with other land demanding projects like schools, hospitals, and industrial layouts etc. which require vast areas of land that abridged the time of wait (Akpan and Ebong, 2021; Döös,2002).

The world is experiencing a constant increase in human population, climate change which is impacting on the agroecosystems, high cost of mineral fertilizers, other farm inputs and world economy which has also impacted on every human economic and lives especially small scale farmers who constitute about 80% of labourin agricultural crop production (Chiaka *et al.* 2022; Babura *et al.* 2017; Mgbenka and Mbah, 2016).

Farmers' desire to increase crop yield and maximize soil nutrients, led to a number of improvement on the older methods for example shifting cultivation, crop rotation etc., which brought about some innovations of planting some desirable food crops and trees combinations to improve the soil texture, structure and keep the soil in a healthier condition for crop growth, development and yield; other agro allied activities and generally the environment which in turn benefit more from the practices without leaving the farmland to rest or fallow. The practice of combining trees or shrubs with crop production brought about the term agroforestry concept in the late 1970s (Atangana *et al.* 2014; Nair *et al.* 2021; Somarriba, 1992).

According to Kang and Gutteridge (1998) and Cooper *et al.* (1996) to cultivate the soil continuously for crop production with little or no fertilizer recommended the planting of leguminous trees and shrubs for example *Cajanus cajan* (Linn.) Mill sp., *Flemingia macrophylla* (Willd.) Merr., *Parkia biglobosa* (Jacq.) Benth., *Acacia auriculiformis* A. Cunn. ex Benth., *Albizia lebbeck* (L.) Benth. and *Leucaena leucocephala* (Lam.) de Wit.

There are some other agroforestry trees that serves dual purposes for example whose leaves are sometimes harvested and given to animals as feed, timber for construction, electricity and communication poles and the supply to other industrial uses for example *Gmelina arborea* Roxb. ex Sm *(Melina)* wood used for tables and doors, Tectona *grandis* L.f. (Teak) wood for boxes and platforms for export containers, *Ecalyptus* spp. log as poles, *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. fruit as food etc., whose leaves and other

Scientia Africana, Vol. 23 (No. 4), October, 2024. Pp 303-316
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

parts drops on the bear ground directly or indirectly and form manure over time or packed and heaped inside pit dugged into the ground for them to undergo decay and later unpacked and sprayed out on farmland as manure ploughed together along with soil.

At times some of these agroforestry trees by-products serve as food and income generation to farmer at maturity, fruits or seeds which are eaten directly, planted in nursery bags and later sold to other farmers. There are evidences that this system contributes to sustainable land management practices of improving quality and health status of soil according to Hombegowda *et al.* 2022, Ferdush *et al.* 2019 and Pinho *et al.* 2012).

This system enhances soil organic carbon; improve soil nutrient availability and soil fertility due to the presence of leaf liters in the agroecosystems (Pinho *et al.* 2012; Tsufac *et al.* 2019), soil microbial dynamics, with positive influence on soil health (Dollinger and Jose, 2018) and easy movement of water and air into the soil**.**

The objective of this present study is to appraise mineral content of soil samples collected under seven plant species used as agroforestry trees namely *Gmelina arborea* Roxb.; *Treculia africana* Decne., *Tectona grandis* Linn. f., *Pentaclethera macrophylla* Benth., *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill., *Mangifera indica* Linn., *Annona muricata* Linn. and Fallow farm land as control in University of Port Harcourt, Choba, Rivers State, Nigeria.

MATERIALS AND METHODS

Study site

The study was carried out at University of Port Harcourt, Choba in Obio/Akpor Local Government Area Council, Rivers State-Nigeria. Coordinates: latitude 4°8729'N and 4°55'N Longitudes 7°0011 in the Niger Delta wetland of Southern Nigeria. Climatic weather condition categorized by a tropical monsoon climate, mean annual temperature of 25 to 28°C and annual rainfall of over 3000 mm. Humidity is very high with an annual mean of 85% while the soil is sandy or sandy loam.

Soil samples collection

Soil samples were collected at random under individual agroforestry trees across the various arable farm lands at the depth of 0-15cm. Soil samples collected were air dried in the laboratory from which composite samples were taken for laboratory analysis. Eight soil samples sent out for analysis were as follows: fallow farm land as control; *G. arborea*, *T. africana*, *T. grandis*, *P. macrophylla*, *I. gabonensis*, *M. indica* and *A. muricata*.

Soil analysis

Composite soil samples prepared into coarse and fine soil which were sent to ANALAB Laboratory Services Limited in Ibadan, Oyo State Nigeria for complete physical and chemical analysis employing standard methods for soil analysis. Soils pH 1:1 soil-water ratio method, measured with EQUIP-TRONICS digital pH meter model EQ-610. Nitrogen estimated by titration of distillation after Kjeldahl, Phosphorus in the soil was measured with the perchloric corrosive albimilation strategy technique. Available Potassium was analyzed by using molybdenum blue colorimetry. Soil organic matter was measured with the potassium dichromate oxidation external heating method. Soil particle size was carried out using hydrometer method and measured with a standard hydrometer, ASTM No.1. 152H-type with Bouyoucos scale in g L-1. Exchangeable cations were extracted from the soil using an extracting solution (1 N NH4OAc) at pH 7.0, and analyzed with AA (Atomic absorption) for the soil cations. Contents in 1/20 dilution (sample/distilled water) soil digests were measured by reading their absorbance on a UNICAM 969 Atomic Absorption Spectrophotometer at 766.5, 422.7 and 285.2 nm respectively. Sodium content in 1/20 diluted sample determined by reading the absorbance at 248.3 nm. The exchangeable acidity (H++ Al3+) in the soil was extracted with 1M KCl. Solution of the extract was titrated with 0.05M NaOH to a permanent pink end point using phenolphthalein as indicator. Amount of base (NaOH) used is equivalent to the total amount of exchangeable acidity (H++Al3+) in the aliquot taken. The total sum of exchangeable bases (Ca2+ + Mg2++ K+ +Na+) and total exchangeable acidity (H+ + Al3+) gave the effective cation exchangeable capacity (ECEC).

RESULTS

Table 1, revealed various values obtained from the soil parameters evaluated on the soil samples collected from the seven agroforestry trees planted and fallow farm land serving as control, means to improve soil texture, structure and soil nutrients through dropping of leaves, twigs and fruits which decay and accumulate overtime; which provide continuous flow of nutrients into the soil and in turn used by plants, other soil organisms within the agroecosystems. Table 1, also revealed individual proportion of these elements and compared across different soil sources of agroforestry trees under investigation.

Table 1: Results of soil parameters evaluated from different soilsources

	Fl	Ma	Ta	Tg	Pm	Ig	Mi	Am
pH(1:1)	5.60	4.70	5.40	4.60	4.50	4.50	4.50	4.80
%N	0.10	0.10	0.14	0.13	0.21	0.13	0.08	0.12
%OC	1.70	1.60	2.40	2.30	3.40	1.30	1.40	2.20
EC (µS/cm)	151.0	91.0	146.0	88.0	141.0	99.0	89.0	133.0
P (mg/kg)	38.40	19.60	72.10	32.90	72.50	61.10	31.70	20.0
Mn (mg/Kg)	87.71	52.54	111.02	46.27	81.01	90.22	46.78	82.59
Fe (mg/Kg)	40.51	97.52	65.45	67.32	138.47	42.46	68.63	21.51
Cu (mg/Kg)	1.31	1.25	0.82	1.14	1.53	1.24	1.41	0.80
Zn (mg/Kg)	2.82	5.93	8.08	2.44	2.55	2.54	1.86	5.73
%Sand	78.0	70.0	80.0	70.0	82.0	76.0	82.0	88.0
%Silt	12.50	16.50	10.50	16.50	10.50	12.50	8.50	4.50
%Clay	9.50	13.50	9.50	13.50	7.50	11.50	9.50	7.50
Ca (cmol/Kg	0.88	0.74	3.43	0.59	1.75	0.90	0.68	2.14
Mg (cmol/Kg)	0.32	0.32	0.70	0.27	0.82	0.48	0.24	1.00
K (cmol/Kg)	0.10	0.07	0.14	0.09	0.15	0.07	0.08	0.07
Na (cmol/Kg)	0.38	0.35	0.37	0.40	0.38	0.35	0.36	0.35
Acidity (cmol/Kg)	9.40	12.55	5.15	16.90	14.65	13.70	11.35	4.05
Al (cmol/Kg)	1.50	2.00	1.60	2.80	1.60	2.35	1.60	1.10
ECEC (cmol/Kg)	12.57	16.03	11.39	21.10	19.36	17.84	14.31	8.70

Legend: Fl (*Fallow* land), Ma (*M. arborea*), Ta (*T. africana*), Tg (*T. grandis*), Pm (*P. macrophylla*), Ig (*I. gabonensis*), Mi (*M. indica*) and Am (*A. muricata*)

Soil samples pH

The pH values across the evaluated soils revealed the highest value 5.6 in fallow land and the smallest 4.5 from *P. macrophylla, I. gabonensis* and *M. indica*.

Percentage Sand, Silt and Clay

The percentage sand varied from 70 % in the soil collected from *M. arborea* and *T. grandis* to 88% in the soil collected from *A. muricata*. Silt revealed its highest value 16.5% from *M. arborea* and *T. grandis*, while smallest value of 4.5% from *A. muricata*. Clay soil highest values of 13.50% were from *M. arborea and T. grandis*, while smallest values of 7.50% were from *P. macrophylla and A. muricata.*

Scientia Africana, Vol. 23 (No. 4), October, 2024. Pp 303-316
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

Percentage Nitrogen (N) and Organic carbon (OC)

The percentage nitrogen in soil samples collected under *P. macrophylla* 0.21% was the highest while the least was from *M. indica* 0.08%. Organic carbon content of the soil samples 3.4% collected from soil under *P. macrophylla* was the highest, and the least was from *I. gabonensis* 1.30%.

Phosphorus (P) and Potassium (K)

Phosphorus highest value of 72.50 (mg/Kg) was from *P. macrophylla* and least 20(mg/Kg) from *A. muricata*. Potassium highest 0.15(cmol/Kg) was from *P. macrophylla* while the least 0.07(cmol/Kg) were from *M. arborea*, *I. gabonensis* and *A. muricata* respectively.

Electrical conductivity (EC) and Effective cation exchange capacity (ECEC)

Electrical conductivity (EC) of these soils revealed 151.0(µS) cm as the highest from fallow farmland and the least was from *T. grandis* with 88.0(µS) cm respectively. Effective cation exchange capacity (ECEC) highest and least values of 21.10 and 8.70 (cmol/Kg) were for *T. grandis* and *A. muricata* respectively.

Manganese (Mn), Iron (Fe), Cupper (Cu) and Zinc (Zn) contents

Among these metals Manganese with 112.02 mg/Kg, recorded under *T. africana* as the highest and smallest concentrations of 46.27mg/Kg and 46.78 mg/Kg were recorded under *M. indica* and *T. grandis* respectively. Iron revealed highest as 138.47mg/Kg and 21.51 mg/Kg smallest value from *P. macrophylla* and *A. muricata* respectively. Copper highest was 1.53mg/Kg and smallest 0.80 mg/Kg from *P. macrophylla* and *A. muricata*. Zinc highest and least was 8.08mg/Kg and 1.86 mg/Kg from *T. africana* and *M. indica* respectively.

Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na) and Aluminum (Al) contents

Calcium highest and smallest values of 3.43 (cmol/kg) and 0.59 (cmol/kg) *T. africana* and *T. grandis* respectively. Magnesium highest and smallest values 1.00(cmol/Kg) and 0.24(cmol/Kg) *M. indica* and *A. muricata* respectively. Sodium highest of 0.40(cmol/Kg) and smallest value 0.35(cmol/Kg) were recorded from *T. grandis, M. arborea*, *I. gabonensis* and *A. muricata* respectively and followed by 0.38(cmol/Kg) from fallow farmland and *P. macrophylla* and closely followed by *T. africana* and *M. indica* with 0.37 and 0.36 (cmol/Kg) respectively.

However, acidity value of 16.90(cmol/Kg) being the highest *T. grandis* and smallest 4.05(cmol/Kg) *A. muricata* respectively. Aluminum (Al) highest value of 2.80(cmol/Kg) in *T. grandis* and smallest 1.10(cmol/kg) from *A. muricata*.

Soil nourishes and supports the growth and development of plant to maturity and for fruit and seed bearing, and at intervals it could be harvested at tender age while growing and developing. It supplies micro and macro elements that are required in different proportions for plant growth, development and bearing of fruit and seed. The accessibility or lacks of these elements are at times noticeable on the plant performance and productivity at the end of the growing season (Ahmed *et al.* 2024, Kumar*et al.* 2021).

DISCUSSION

Soil nutrient comes through two ways either from the parent rock materials or from the decay of plants, animals, insects and other materials within the agroecosystems. However, accessibility of these elements depends on the pH of the soil because pH is considered as master variable in the soil which affects lots of chemical and biological reactions influencing solubility, readiness and useable nature for the uptake of plant as required (Penn *et al.* 2019, Barrow and Hartemink, 2023).

pH

Soil samples pH results revealed that fallow land which has been under fallow for few years has the highest pH value of 5.6 followed by *T. africana* 5.4 and *A. muricata* 4.8, while others *M. arborea*, *T. grandis*, *I. gabonensis*, *P. macrophylla* and *M. indica* followed in this order of pH values 4.7, 4.6, 4.5, 4.5 and 4.5 respectively.

It also revealed that pH values of soils are strongly and moderately acidic, hence would support almost all crops as the pH values are within 4.5 and 5.6. Under these situations the soils would accommodate a good number of crops coupled with availability of other elements in the soil, thus when acidity is below 4.5, the soil becomes increasingly difficult to produce food crops according to Harter (2007). As soil pH declines, the supply of most plant nutrients decreases while aluminum and a few micronutrients become more soluble and toxic to plants (Harter, 2007). These problems are particularly acute in humid tropical regions that have been highly weathered or degraded (Harter, 2007).

Percentage Sand, Silt and Clay

Soil is made up of mineral particles, organic materials, air, water and living things and all interact with each other. Sand, silt and clay in different percentage proportions constitute various soil types, and in effect determine plant that can flourish on them. Sand content from the soils are between 70% and 88%, while that of silt is between 4.5% and 16.5% and clay is 7.5% and 13.5%. This revealed that the soils are of sandy loam in nature. This is in agreement with earlier findings of Ekeke and Okonwu (2013) and Ogazie *et al.* (2022) from the soils of University of Port Harcourt and environs. These soil types accommodate quite a number of plants and crops during the planting season as observed by Ogazie *et al.* (2022).

% N and %OC

Nitrogen a member of the three macronutrients required by plant in large quantity to grow, develop and also enables plant to produce fruit and seed. The need of nitrogen varies from plant to plant and it is available naturally or artificially added to the soil. Its presence or absence could be seen from the physical appearance of the plant that the supply of nitrogen is limited in the soil. *P. macrophylla* has the highest yield of nitrogen 0.21% more than fallow farmland 0.1% which has rested for a number of years before clearing.

It was closely followed by *T. africana* with % 0.14, *I. gabonensis* 0.13%, *T. grandis* 0.13%, *A. muricata* 0.12%, *M. arborea* 0.10% and the smallest *M. indica* 0.08%. *P. macrophylla* is a tree legume and fixes nitrogen, thus the small numerous leaves that falls from it form thick cover on the top soil which decay to release nitrogen in the leaves to the soil. Thus, could be responsible for the high value of Nitrogen in the soil (Zhao *et al.* 2022).

EC (µS) cm, ECEC (cmol/Kg)

EC measures the salinity and electrically charged nutrient ions in a solution (Bluelab, 2015). EC values are influenced by clay and mineral content, soluble salts, soil water content, bulk density, organic matter and temperature (Corwin and Lesch, 2005). It is an important parameter which reveals the extent of soil's ability to transmit water and nutrients. The result from the tested soils samples from the agroforestry trees and fallow land control revealed that fallow farm land has a value of 151.0 EC (µS/cm) as the highest while the smallest *T. grandis* 88.0 EC (µS/cm).

Others followed in this order as *T. africana* 146.0 EC (µS/cm), *P. macrophylla* 141.0 EC (µS/cm), *A. muricata* 133.0 EC (µS/cm), *I. gabonensis* 99.0 EC (µS/cm), *M. arborea* 91.0 EC (µS/cm), *M. indica* 89.0 EC (µS/cm). The values obtained are within the permissible limits as low EC values indicate a low concentration of soluble salts and good soil fertility, while high values suggest excessive

Scientia Africana, Vol. 23 (No. 4), October, 2024. Pp 303-316
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

salt accumulation or poor drainage which can negatively affect plant growth (Shahid *et al.* 2018).

Effective cation exchange capacity (ECEC), in the soil indicates soil fertility status and its ability to supply and hold on to exchangeable cations by electrical attraction which are positively charged for example the five most abundant are calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^{+}), sodium (Na^{+}) and aluminum (Al^{+++}), and the availability of all to plant depends on the soil pH. Nutrient to the plant roots involves the exchange of cations and anions of clay minerals, inorganic compounds, and organic matter influencing soil nutrients availability (Havlin, 2013).

Result of the soil analysis revealed that *T. grandis* with 21.1 (cmol/Kg), a tree with very large and tough leaves as the highest, followed by *P. macrophylla*a tree legume with numerous tiny leaves, pods and twigs which cover the top soil and decay rapidity releasing its nutrient content to the soil has the value of 19.4(cmol/Kg), *I. gabonensis* 17.8(cmol/Kg), *M. arborea* 16.0 (cmol/Kg), *M. indica* 14.3(cmol/Kg), fallow farmland 12.6(cmol/Kg), *T. africana* 11.4 (cmol/Kg) and smallest *A. muricata* 8.7 (cmol/Kg).

Mn, Fe, Cu and Zn (mg/Kg)

Microelements are required in trace amount in the soil as they play important roles in plant for normal growth, development and optimal processes (Kumar *et al.* 2021). Micronutrients which are needed only in trace amounts are Fe, Mn, B, Zn, Cu, Mo, Cl, Na, Ni, Si, Co and Se. Nevertheless, this work evaluated Mn, Fe, Cu and Zn from the agroforestry farms soil samples (Table 1). The highest value of Mn 111.02(mg/Kg) was from *T. africana*, followed by *I. gabonensis* with 90.22(mg/Kg). Others are fallow farmland 87.71(mg/Kg), *A. muricata* 82.59(mg/Kg), *P. macrophylla* 81.01(mg/Kg), *M. arborea* 52.54(mg/Kg), *M. indica* 46.78 (mg/Kg) and *T. grandis* 46.27 (mg/Kg) respectively.

Manganese (Mn) is required for activation of enzymes processes and supports the conversion of nitrates into a readily form for plant and perform a role in chlorophyll production (Mousavi *et al.* 2011). The amount of available manganese is influenced by soil pH, organic matter, moisture, and soil aeration (Schulte and Kelling, 1999). According to *Rashed et al.* (2019) most plant species require between 10-20mg/Kg^{-1}, these results were far above this requirement, indicating remarkable contribution of the agroforestry trees and fallow farmland used as control.

Iron (Fe) present in the agroforestry trees sampled soils revealed as follows *P. macrophylla* with the highest value of 138.5(mg/Kg), *M. arborea* 97.52(mg/Kg), *M. indica* 68.63 (mg/Kg), *T. grandis* 67.32 (mg/Kg), *T. africana* 65.45(mg/Kg), *I. gabonensis* 42.46 (mg/Kg), fallow farmland 40.51 (mg/Kg) and *A. muricata* 21.51 (mg/Kg) respectively. Iron (Fe) is involved in chlorophyll manufacturing processes, works in close collaboration with soil pH and its deficiency in chlorophyll synthesis causes chlorosis (Morrissey and Guerinot, 2009, Rout and Sahoo,2015). The values obtained were within the ranges of 21.51 to 138.47(mg/Kg) and comparable with what was obtained by Mallarino (2005).

Copper (Cu) is essential for numerous enzymatic activities in plants for example chlorophyll leading to photosynthesis, respiration, antioxidant system and seed production; while deficiency of copper would lead to increased susceptibility to diseases like ergot, which can cause significant yield loss in small grains (Yruela,2005). Thus values obtained from the soil analysis revealed *P. macrophylla* 1.53 (mg/Kg), *M. indica* 1.41(mg/Kg), fallow land 1.31(mg/Kg), *M. arborea* 1.25(mg/Kg), *I. gabonensis* 1.24(mg/Kg), *T. grandis* 1.14(mg/Kg), *T. africana* 0.82 and *A. muricata* respectively.These values are far below the amount between 6-10 mg/Kg of Cu required by plant according to Hasnine *et al.*(2017) and also far below the maximum permissible level of 36(mg/Kg)(Denneman and Robberse, 1990) and (WHO, 1996).As a result could be supported where there is evident in short supply to the reach of plant.

Zinc (Zn) is a driving force relative to enzymatic activities in plant leading to cell growth, differentiation and metabolism, while its deficiency reduces carbohydrate, protein and chlorophyll formation significantly (Saleem *et al.* 2022). The result from the soils analysis revealed that *T. africana* has the highest value of Zn 8.08(mg/Kg), followed by *M. arborea* 5.93(mg/Kg), *A. muricata* 5.73(mg/Kg), fallow farmland 2.82 (mg/Kg), *P. macrophylla* 2.55(mg/Kg), *I. gabonensis* 2.54(mg/Kg), *T grandis* 2.44(mg/Kg) and *M. indica* (mg/Kg) respectively.

These values when compared with the maximum value of 50(mg/Kg) from unpolluted soil as documented by Denneman and Robberse (1990), Netherlands ministry of Housing (1994) and WHO (1996) uncovered that values from the soils were very low and would not interfere with plant development processes while too little would lead to malnutrition and stunted growth (Sharma, 2013).

Ca, Mg, K, Na and Al contents

T. africana with 3.43 Ca (cmol/Kg) highest value amid the soil sources followed by *A. muricata* 2.14Ca (cmol/Kg), and *P. macrophylla* with 1.75 Ca (cmol/Kg). These three plants have the capacity to provide Calcium to the soil more than the other agroforestry plants and fallow farmland. These agroforestry tree roots have the capacity to dig deep down the subsoil for more nutrients (Sileshi, 2014, Vanlauwe *et al.* 2005) and also their leaves and twigs would have also contributed to the increase in values obtained. Others were *I. gabonensis*, fallow land, *M. arborea*, *M. indica* and *T. grandis* with 0.90, 0.88, 0.74, 0.68 and 0.59(cmol/Kg) respectively. The rest of agroforestry plants also contributed to Calcium based on their ability and in addition to other elements within the soil in the agroecosystems (Sileshi, 2014).

A. muricata a shrubby tree plant gave the highest value of Magnesium 1.00 Mg (cmol/Kg), closely followed by *P. macrophylla* 0.82 (cmol/Kg), a leguminous tree and followed by *T. africana* 0.70 (cmol/Kg) a tree which can form dense canopy of leaves with deep green coloration. Other trees were not too different from fallow farmland value of 0.32 Mg (cmol/Kg) which has rested for few years when compared with *M. arborea* 0.32 Mg (cmol/Kg), *T. grandis* 0.27 Mg (cmol.), *I. gabonensis* 0.48 Mg (cmol/Kg) and *M. indica* 0.24 Mg (cmol/Kg) respectively. Arable farmland not continuously cultivated yearly provides litters in the course of the resting period which ameliorate back the soil nutrients lost in the previous cropping season.

These minerals are essential and play very important roles in soil fertility sustainability because their presence in the soil foster plant growth, development and yield production, for example Magnesium (Mg) is chlorophyll initiator, transportation and utilization of photoassimulates, enzyme activation and protein synthesis (Ishfaq *et al.* 2022).

Potassium from the agroforestry trees and fallow farmland soils evaluated revealed that *P. macrophylla* has the highest value of 0.15 K (cmol/Kg), *T. africana* with 0.14 K (cmol/Kg), while fallow farmland gave 0.10 K (cmol/Kg), *T. grandis*, *M. indica*, *M. arborea* and *A. muricata* with 0.09, 0.08, 0.07 and 0.07 K (cmol/Kg) respectively.

The result from the analysis revealed further the nutritive contributions of the individual agroforestry trees of which *P. macrophylla* a tree legume whose leaves decay within a short time and release its mineral content to the soil contributed the highest value of potassium, however, *T. africana* followed closely, a tree with so much leaves and forms lots of leaf litters above ground with conducive and right conditions, other elements in the right proportion with right pH value will decay to release its nutrients to the soil (Couˆteaux *et al.* 1995).

Scientia Africana, Vol. 23 (No. 4), October, 2024. Pp 303-316
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

The outcome from the soil samples evaluation revealed that fallow farmland was 0.02 less than the highest value of 0.40 Na (cmol/Kg) from *T. arborea*. The other values also followed similar pattern in terms of Na values from *P. macrophylla* 0.38 Na (cmol/Kg), *T. africana* 0.37 Na (cmol/Kg), *M. indica* 0.36 Na (cmol/Kg), *M. arborea* and *A. muricata* 0.35 Na (cmol/Kg) respectively. Sodium is non-essential for most plants, sodium (Na+) can be beneficial to plants in many conditions, particularly when potassium (K+) is deficient (Frans, 2014). As such it can be regarded as a 'non-essential' or 'functional' nutrient to plant.

Al is one of those common metals found in the environment, which occurs natural and through anthropogenic activities. It is a metal that readily combines with the environment, with water at different pH levels especially at extremely strong acidic condition which makes it available for plant uptake. The acidity of the soluble water forms could make its presence to increase and these are evident in some plants like tea and coffee beans (Crisponi *et al*. 2013).

The values of aluminum obtained from the evaluation are quite small which could have gotten into the environment through anthropogenic activities and parents' soil. The fallow farmland revealed traces of aluminum at the value of 1.5(cmol/Kg). Yet, *T. grandis* has a value of 2.80 Al (cmol/Kg) as the highest followed by *I. gabonensis* 2.35 Al (cmol/Kg), *M. arborea* 2.0 Al (cmol/Kg), *P. macrophylla* 1.6 Al (cmol/Kg), *T. africana* 1.6 Al (cmol/Kg), *M. indica* 1.6 Al (cmol/Kg) and the smallest *A. muricata* 1.10 Al (cmol/Kg).

According to Ofoe *et al.* (2023), the presence of aluminum in the soil stimulate growth and mitigating biotic and abiotic pressures depending on the concentration, exposure time, plant species, developmental age and growing circumstances and sometimes it promotes root growth and development as found in some tea varieties (Sun *et al.* 2020) due the presence of Al^{3+} which in its absence does not encourage root growth and development. On the other hand, in a situation of reduced pH value below 4.5, its presence in the soil becomes poisonous to the plant preventing cell extension, cell division and transport (Mossor-Pietraszewska, 2001).

CONCLUSION

Effort to reduce impact on environment through clearing less of virgin forest, which led to soil degradation, because of cultivation and planting of crop to feed man. Long time use of arable farm land contributes to decline in yield of crop due to over use, poor soil health status and climate change. Hence older methods of crop rotation, shifting cultivation, application of farmyard manure etc., for sustaining soil fertility were improved upon with the addition and adoption of agroforestry trees and crop planting for continuous supply of nutrients to soil for plant uptake for greater crop harvest and thus reduce impact on the agroecosystems. This study was carried out on selected agroforestry trees to access their potentials to contribute macro and micro nutrients to the soil and make it available for plant use. The result revealed the level of macro and micro nutrients present in those soil samples evaluated which indicated the extent of minerals contributed by individual agroforestry tree to the soil for optimally plant growth and development. The outcome encourages agroforestry tree planting along with crop as it reduces use of inorganic fertilizer, pollution and safeguard the environment.

Conflict of Interest

The authors declare no conflict of interest.

REFERENCES

AbdelRahman, M.A.E. (2023). An overview of land degradation, desertification and sustainable land management using GIS and remote sensing applications. *Rendiconti Scienze eNaturali*, 34: 767–808,https://doi.org/10.1007/s12210-023-01155-3.

Adenle, A.A., Eckert, S., Adedeji, O.I., Ellison, D. and Speranza, C.I. (2020). Human-induced land degradation dominance in the Nigerian Guinea Savannah between 2003 – 2018, *Remote Sensing Applications*: *Society and Environment*, Volume 19, 2020,100360 ISSN 2352-9385,https://doi.org/10.1016/j.rsase.2020.100360.

Ahmed, N., Zhang, B., Chachar, Z., Li, J., Xiao, G., Wang, Q., Hayat, F., Deng, L., Narejo, M.N., Bozdar, B.and Tu,P. (2024).Micronutrients and their effects on Horticultural crop quality, productivity and sustainability,*ScientiaHorticulturae*,Volume 323, 2024,112512, ISSN 0304-4238,https://doi.org/10.1016/j.scienta.2023.112512.

Akpan, S. B. and Ebong, V. O. (2021). Agricultural land use and population growth in Nigeria. The need for synergy for a sustainable agricultural production. *Journal of Agribusiness and Rural Development*, 3(61): 269–278. http://dx.doi. org/10.1 730 6/J.JARD.2021.01424.

Atangana, A., Khasa, D., Chang, S. andDegrande, A. (2014). Definitions and Classification of Agroforestry Systems. In: *Tropical Agroforestry*. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-7723-1_3.

Babura, B.S., Isah, S.D. and Chamo, A.M. (2017). Role of smallholder farmers in Nigeria's food security. *Journal of Agricultural Science* Volume 7(1): 1-5. http://www.scholarly-journals.com/SJAS,ISSN 2276-7118.

Barrow, N.J. and Hartemink, A.E. (2023). The effects of pH on nutrient availability depend on both soils and plants, *Plant and Soil* 487(1-2):1-17, https://doi. org/10.1007/ s11104-023-05960-5.

Bluelab. (2015). Conductivity pen. Care and use guide. Retrieved from https://www.bluelab.com/Product-Manuals/EC-ppm-Pen-Manuals/Bluelab-ppm Pen ManualENG-OCT12.aspx.

Chiaka, J.C., Zhen, L., Yunfeng, H., Xiao, Y., Muhirwa, F and Lang, T. (2022). Smallholder farmers contribution to food production in Nigeria. *Frontiers in Nutrition*, Volume 9, 2022. https://www.frontierin.org/articles/10.3389/fnut.2022.916678.

Cooper, P. J. M., Leakey, R. R. B., Rao, M. R. and Reynolds, L. (1996). Agroforestry and the mitigation of land degradation in the humid and sub-humid tropics of Africa. *Experimental agriculture*, *32*(3): 235-290.

Corwin, D.L. and Lesch, S.M. (2005). Apparent soil electrical conductivity measurements in agriculture. *Science Direct*, 46 (1-3): 11-43.

Couˆteaux, M-M., Bottner, P. and Berg, B.(1995).Litter decomposition, climate and liter quality, *Trends in Ecology & Evolution*, Volume 10 (2): 63-66,ISSN 0169-5347,https://doi.org/10.1016/S0169-5347(00)88978-8.

Crisponi, G., Fanni, D., Gerosa, C., Nemolato, S., Nurchi, V.M., Crespo-Alonso, M., Lachowicz, J.I. and Faa, G. (2013). The meaning of Aluminum exposure on human health and Aluminum-related diseases. *Biomolecular Concepts*, 4(1):77–87,https: //doi. Org / 10.1515/bmc-2012-0045.

Denneman, C.A. and Robberse, J.G. (1990) Ecotoxicological risk assessment as a base for development of soil quality criteria. In: *Contaminated Soil'90*, Springer, Dordrecht, pp. 157-164. https://doi.org/10.1007/978-94-011-3270-1_28.

Dollinger, J. and Jose, S. (2018). Agroforestry for soil health. *Agroforestry Systems*, 92:213-219. https:// doi.org/101007/s10457-018-0223-9.

Döös, B.R. (2002). Population growth and loss of arable land. *Global Environmental Change* 12(4):303-311, DOI: 10.1016/S0959-3780(02)00043-2.

Scientia Africana, Vol. 23 (No. 4), October, 2024. Pp 303-316
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

Ekeke, C. and Okonwu, K. (2013). Comparative Study on Fertility Status of Soils of University of Port Harcourt, Nigeria. *Research Journal of Botany*, 8: 24-30.

Fadairo, O., Olajuyibe, S., Osayemi, O., Adelakun, O., Olaniyan, O., Olutegbe, S. and Adeleke, O. (2020). Climate Change, Rural Livelihoods and Ecosystem Nexus: Forest Communities in Agro-ecological zones of Nigeria. In: Leal Filho, W., Oguge, N., Ayal, D., Adelake, L.and da Silva, I. (Eds).*African Handbook of Climate Change Adaptation*. Springer, Cham. https://doi.org/10.1007/978-3-030-42091-8_155-1.

Ferdush, J., Karim, M.M., Noor, I.J., Jui, S.A., Ahamed, T. and Saha, S.R. (2019). Impact of alley cropping system on soil fertility. *International Journal of Advanced Geosciences*, 7 (2) : 173-178.

Frans J. M.M. (2014). Sodium in plants: perception, signaling, and regulation of sodium fluxes, *Journal of Experimental Botany*, Volume 65(3):849–858, https://doi.org/10.1093/jxb/ert326.

Harter, R.D. (2007). Acid soils of the tropics. *ECHO Technical Note*. http:// www. echonet .org/

Hasnine, M.T., Hudu, M.E., Khatun, R., Saadat, A.H.M., Ahasan, M., Akter, S., Uddin, M.F., Monika, A.N., Rahman, M.A. and Ohiduzzaman, M. (2017). Heavy metal contamination in agricultural soil at DEPZA, Bangladesh. *Environment and Ecology Research* 5(7):510-516. https://doi.org/10.13189/eer.2017.050707.

Havlin, J.L. (2013). Fertility. *Reference Module in Earth Systems and Environmental Sciences*, Elsevier, 2013, ISBN 9780124095489, https://doi.org/10.1016/B978-0-12-409548-9.05162-9.

Hoffmann, I., Gerling, D., Kyiogwom,U.B. and Mané-Bielfeldt,A.(2001) Farmers' management strategies to maintain soil fertility in a remote area in northwest Nigeria,*Agriculture, Ecosystems &Environment*, Volume 86(3): 263-275,ISSN 0167-8809,https://doi.org/10.1016/S0167-8809(00)00288-7.

Hombegowda, H.C., Adhikary, P.P., Jakhar, P. and Madhu, M. (2022). Alley Cropping Agroforestry System for Improvement of Soil Health. In: Shit, P.K., Adhikary, P.P., Bhunia, G.S. and Sengupta, D. (Eds). *Soil Health and Environmental Sustainability*. *Environmental Science and Engineering*. Springer, Cham. https://doi.org/10.1007/978-3-031-09270-1_23. https://doi.org/10.1016/j.foreco.2020.118127.

Ishfaq, M., Wang, Y., Yan, M., Wang, Z., Wu, L., Li, C. and Li, X. (2022). Physiological Essence of Magnesium in Plants and Its Widespread Deficiency in the Farming System of China. *Frontiers in plant science*, 13, 802274. https:// doi.org /10.3389/fpls.2022.802274.

Kang, B.T. and Gutteridge, R.C. (1994). "Forage tree legumes in alley cropping systems." In Gutteridge, R.C. and H.M. Shelton (Eds). *Forage Tree Legumes in Tropical Agriculture*. *Tropical Grassland Society of Australia*, St. Lucia, QLD, Australia. http//www.fao.org/ag/AGP/AGPC/doc/Publicat/Gutt-shel/x5556e00.htm.

Kgosikoma,O.E., Mojeremane, W. and Harvie, B.A.(2013). Grazing management systems and their effects on savanna ecosystem dynamics: A review. *Journal of Ecology and the Natural Environment*, Vol. 5(6): 88-94, DOI: 10.5897/ JENE 2013 .0364ISSN 2006-9847.

Kumar, S. Kumar, S. and Mohapatra, T. (2021). Interaction between Macro- and Micro-Nutrients in Plants. *Front. Plant Sci.* 12:665583. https:// doi: 10.3389/fpls.2021.665583.

Mallarino, A.P. (2005). Testing of soils, (Ed). Daniel Hillel, *Encyclopedia of Soils in the Environment*, Elsevier, 2005, pp. 143-

149, https: // doi.org/10.1016/B0-12-348530-4/00302-7.

Mayer, M., Prescott, C.E., Abaker,W.E.A., Augusto, L., Cécillon, L., Ferreira, G.W.D., James, J., Jandl, R., Katzensteiner, K., Laclau, J-P., Laganière, J., Nouvellon,Y., Paré, D., Stanturf, J.A., Elena I. Vanguelova, E.I. and Vesterdal, L.(2020).Tamm Review: Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis, *Forest Ecology and Management*, 466, [118127]. https:// doi.org/10. 1016/j. foreco. 2020.118127.

Mgbenka, R.N. and Mbah, E.N. (2016). A review of smallholder farming in Nigeria: Need for transformation. *International Journal of Agricultural Extension and Rural Development Studies*, Volume 3(2):43-54.

Morrissey, J. and Guerinot, M. L. (2009). Iron uptake and transport in plants: the good, the bad, and the ionome. *Chemical reviews*, 109(10): 4553–4567,https:// doi.org/ 10.1021/ cr900112r.

Mossor-Pietraszewska, T. (2001). Effect of aluminum on plant growth and metabolism. .*ActaBiochimicaPolonica*, *48*(3): 673–686.

Mousavi, S.R., Shahsavari, M. and Rezaei, M. (2011). A General Overview on Manganese (Mn) Importance for Crops Production, *Australian Journal of Basic and Applied Sciences*, 5(9): 1799-1803.

Nair, P.K.R., Kumar, B.M. and Nair, V.D. (2021). Definition and Concepts of Agroforestry. In: An Introduction to Agroforestry. Springer, Cham. https://doi.org/10.1007/978-3-030-75358-0_2.

Netherlands Ministry of Housing (1994) Dutch Intervention Values for Soil Remediation (Report HQ 94-021). *Environmental Quality Objectives in the Netherlands*, Ministry of Housing, The Hague.

Ofoe, R., Thomas, R.H., Asiedu, S. K., Wang-Pruski, G., Fofana, B. and Abbey, L. (2023). Aluminum in plant: Benefits, toxicity and tolerance mechanisms. *Frontier Plant Science*, 13:1085998.doi: 10.3389/fpls.2022.1085998.

Ogazie, C.A., Edache, E.B., Agbagwa, I.O. and Ugiomoh, I.G. (2022). Multi-cropping practice: Means to sustainable agriculture in the high humid rainforest agroecology of Southern Nigeria, *International Journal of Science and Technology Research Archive*, 03(01): 066–090, https: //doi. org/10. 53771 /ijstra. 3.1.0066.

Ogazie, C.A., Ochekwu, E .B. and Agbagwa, I.O. (2022). Influence of farming systems practices on physicochemical properties of soils in wet and dry season in University of Port Harcourt, Nigeria, *GSC Advanced Research and Reviews*,11(02): 089–101, https://doi.org/10.30574/gscarr.11.2.0134.

Penn, C.J. and Camberato, J.J. (2019). A Critical Review on Soil Chemical Processes that Control How Soil pH Affects Phosphorus Availability to Plants. *Agriculture* 2019, 9, 120. https://doi.org/10.3390/agriculture9060120.

Pincho, R.C., Miller, R.P., and Alfaia, S. (2012). Agroforestry and the improvement of soil fertility: A view from Amazonia. Applied and Environmental Soil Science Volume 2012, Article ID 616383, 11 pages. https://doi.10.1155/2012/616383.

Prescott,C.E. and Vesterdal, L. (2021). Decomposition and transformations along the continuum from litter to soil organic matter in forest soils,*Forest Ecology and Management*, Volume 498,2021,119522,ISSN 0378-1127, https ://doi.org /10.1016/j. foreco.2021.119522.

Rashed. M.H., Hoque, T.S., Jahangir, M.M.R. and Hashem, M.A. (2019). Manganese as a Micronutrient in Agriculture: Crop Requirement and Management, *Journal of Environmental Science and Natural Resources*, 12(1&2):225-242.

Scientia Africanа, Vol. 23 (No. 4), October, 2024. Pp 303-316
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

Rout, G.R., and Sahoo, S. (2015). Role of iron in plant growth and metabolism. *Reviews in Agricultural Science*, 3:1-24, https:// doi: 10.7831/ras.3.1.

Saleem, M.H., Usman, K., Rizwan, M., Al Jari, H. and Alsafran, M.(2022). Functions and strategies for enhancing zinc availability in plants for sustainable agriculture. *Frontier in Plant Science*, 13:1033092. doi: 10.3389/fpls.2022. 1033092

Schulte, E.E. and Kelling, K.A. (1999). Soil and applied manganese. *Understanding Plant Nutrients*, A2526.

Shahid, S.A., Zaman, M. and Heng, L. (2018). Introduction to Soil Salinity, Sodicity and Diagnostics Techniques. In: Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques. Springer, Cham. https:// doi. org/ 10.1007/978-3-319-96190-3_1.

Sharma, A., Patni, B., Shankhdhar, D. and Shankhdhar, S. C. (2013). Zinc - an indispensable micronutrient. Physiology and molecular biology of plants*: International Journal of Functional Plant Biology*, 19(1): 11–20. https:// doi.org/ 10.1007/s12298-012-0139-1.

Sileshi G.W., Mafongoya, P.L., Akinnifesi, F.K., Phiri, E., Chirwa, P., Beedy, T., Makumba, W., Nyamadzawo, G., Njoloma, J., Wuta, M., Nyamugafata, P. and Jiri O.(2014). Agroforestry: Fertilizer Trees. In: Neal Van Alfen, editor-in-chief. *Encyclopedia of Agriculture and Food Systems*, Vol. 1: 222-234, San Diego: Elsevier; 2014.

Somarriba, E. (1992). Revisiting the past: an essay on agroforestry definition. *Agroforest Systems* 19: 233–240, https://doi.org/10.1007/BF00118781

Stewart, Z.P., Pierzynski, G.M., Middendorf, B.J. and Prasad, P.V. (2020). Approaches to improve soil fertility in sub-Saharan Africa, *Journal of Experimental Botany*, Volume 71(2):632-641, https://doi.org/ 10.1093/jxb/erz446.

Sun, L., Zhang, M., Liu, X., Mao, Q., Shi, C., Kochian, L.V. and Liao, H. (2020). Aluminum is essential for root growth and development of tea plants (*Camellia sinensis*), *Journal of Integrative Plant Biology*, Volume 62 (7): 984–997, https:/// doi/pdf/ 10.11 11/jipb.12942.

Tsufac, A.R., Yerima, B.P.K. and Awazi, N.P. (2019).Assessing the role of Agroforestry in soil fertility improvement in Mbelenka-Lebialem, Southwest Cameroon. *International Journal of Global Sustainability*, Volume 3(1):115. https.doi:10.5296.ijgs.v3i1. 15729.

Vanlauwe, B., Aihou, K., Tossah, B.K., Diels, J., Sanginga, N. and Merckx, R. (2005). *Senna siamea* trees recycle Ca from Ca-rich subsoil and increase the topsoil pH in agroforestry systems in the West African derived savanna zone. *Plant and Soil* l269(1): 285-296. DOI:10.1007/s11104-004-0599-3.

WHO (1996). Permissible Limits of Heavy Metals in Soil and Plants. World Health Organization, Geneva.

Yruela, I. (2005). Copper in Plants. *Brazilian Journal of Plant Physiology*, 17(1):145-156.

Zhao,Y-Y., Li,Z-T., Xu,T. and Lou,A. (2022). Leaf litter decomposition characteristics and controlling factors across two contrasting forest types, *Journal of Plant Ecology*, Volume 15(6): 1285-1301,https ://doi. org/10 .1093 /jpe/ rtac073.