International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 21, No. 1, p. 160-168, 2022

INNSPUB

RESEARCH PAPER OPEN ACCESS

Characterising soil cation exchange capacity (CEC) and base saturation (BS) Under exotic fruity trees in the moist rainforest of Nigeria

Ndakara Ofudjaye Emmanuel[1*], Ohwo Odafivwotu[2]

[1]Department of Geography and Regional Planning, Delta State University, Abraka, Delta State, Nigeria

[2]Department of Geography and Environmental Management, Niger delta University, Wilberforce Island, Bayelsa State, Nigeria

Key words: Ecosystem management, Exchangeable cations, Exotic fruity trees, Rainforest, Soil fertility restoration.

http://dx.doi.org/10.12692/ijb/21.1.160-168 Article published on July 28, 2022

Abstract

Apart from the provision of fruits, exotic trees are capable of restoring soil fertility within rainforest environment. This study characterised soil exchangeable cations (ECs), CEC, pH and BS under *Persea gratissima, Mangifera indica* and *Terminalia cattapa* within Nigerian rainforest. Samples of soils were collected under 15 stands of each exotic fruity tree (EFT) species and rainforest (Rf) using core sampler, and analysed in the laboratory using standard techniques. Data were statistically analysed using the mean, standard deviation, coefficient of variation, analysis of variance and post-hoc test. Soil elements varied under the EFTs and the (Rf). The ECs variation pattern within the topsoil appeared same for magnesium (Mg2+), potassium (K+) and sodium (Na+) where Rf > *T. cattapa* > *M. indica* > *P. gratissima*; but differ from that of calcium (Ca2+) which is *T. cattapa* > *M. indica* > *P. gratissima* > Rf respectively. Within the subsoil, K+ and Na+ showed similar patterns where Rf > *T. cattapa* > *P.gratissima* > *M. indica*, while Ca2+ and Mg2+ patterns differed. The differences in soil variables under EFTs and the Rf were significant at the 0.05 confidence level. The CEC under EFTs are < 10meq/100g, while that of the Rf is > 10meq/100g. While the saturations of hydrogen under EFTs indicate that soils underneath can be productive, the EFTs have the capacity for sustainable restoration of ECs to the rainforest soil, with frequent liming thus their growth should be encouraged.

* **Corresponding Author:** Ndakara Ofudjaye Emmanuel ✉ ndakaraoe@delsu.edu.ng

Introduction

The assessment of CEC and B.S under exotic fruity trees (EFTs) is very vital and of immense importance to soil nutrient restoration in the much degraded rainforest environment. Due to high level of degradation the rainforest which is known to be rich in tree species, is now exposed to soil quality deterioration (Oyebiyi, Ojetade, Muda, and Amusan, 2018; Ndakara and Ofuoku, 2020). Therefore, any exercise geared towards soil nutrient restoration becomes necessary. However, once the indigenous tree species of the rainforest are cut down, their regenerations are not easily achieved within a short term period (Ndakara, 2012). This redirects the need for alternative species of trees which could be grown for the purpose of managing the degraded soil considering their CEC capacity, which defines their ability to provide the soil with the required nutrient cations (Pincus, Ryan, Huertas and Alvarado, 2017; Fabricio *et al.,* 2018). Upon this, the quest for tree species which are exotic to the rainforest but are capable of soil nutrient restoration becomes necessary because their attainment of climax and the time frame it takes to become capable of returning essential nutrients back to soil is shorter in comparison with indigenous rainforest tree species (Ndakara, 2012).

Indeed, soil properties can be modified by the type of tree species contained in a given ecosystem (Phil-Eze, 2010; Pawlik, Burkepile and Thurber, 2016). Several studies have reported variations in soil chemical properties resulting from different tree species contained in ecosystems (Fabio and Reinaldo, 2012; Mori, Isbell, Fujii, Makoto, Matsuoka and Osono, 2016). Tree species affect soil ECs, CEC, pH values and BS percentage (Mueller, Gerber, Johnston, Ray, Ramankutty and Foley, 2012; Gruba, Mulder and Brozek, 2013; Gruba and Mulder, 2015; Galka, Tobolski, Górska and Lamentowicz, 2017). While some species of trees have the capacity to supply soil with higher concentrations of ECs and therefore increase the soil CEC, there are tree species that have low CEC in the soils under them due possibly to low supply of ECs (Crouse, 2015).

Exchangeable cations are very important plant nutrients. Decline in the fertility status of soil when cropped for a long period of time had been attributed to nutrient exhaustion (Komprdová, Komprda, Menšík, Vanková, Kulhavy and Nizzetto, 2016). However, their replenishment are essential aspects of nutrient return to soil in nutrient cycling (Ndakara, 2011; Mueller *et al.,* 2012; Galka *et al.,* 2017). Mori *et al.* (2016), emphasised that CEC is an important determinant of soil's ability and capacity to retain and release elements such as K, Ca, Mg, and Na; While Brown and Lemon (2016) upholds that soil CEC affects its ability and capacity to provide the needed cations to support the growth of plants. As CEC determines the ability and capacity of soil to hold nutrients, it is therefore a major determinant of the level and status of soil fertility. Soils that have high CEC in concentration are capable of holding more cations thus, are more sufficient with respect to the concentrations of K, Ca, Mg, and Na. However, soils that have low CEC are prone to cations deficiency (Komprdová *et al.* 2016; Brown and Lemon, 2016; Kharel *et al.,* 2019). In the bid to determine the soil CEC and BS, Soil pH determination becomes necessary (Marx, Hart, and Stevens, 1999; Fabio and Reinald, 2012). It affects soil nutrients solubility and the absorption of nutrients by the roots of plants (Kardol, Throop, Adkins and De Graaff, 2016; Suzuki *et al.*, 2021). Base saturation is concerned with the fraction of the CEC which basic cations such as K, Ca, Mg and Na occupy (Marx *et al.,* 1999). Base saturation is used to manage soil Na+ and can be utilized to determine soil Mg availability (Fabricio *et al.,* 2018; Kharel *et al.*, 2019). When Na exceeds 15% of the CEC, water and air infiltration into soil reduces, and poor growing conditions may result (Marx *et al,* 1999). Soils that contain high B.S percentage are generally more fertile because they comprise higher concentrations cations K^+, Ca^{2+} and Mg^{2+} for use by plants; and have more pH and therefore buffered more against the acid cations which are from the roots of plants and the processes of the soil which makes it acidic (Gruba and Mulder, 2015; Kharel *et al.,* 2019). Base saturation has been seen as complex soil parameter which approximates the degree of relationships between basic and acidic cations in relation to other soil properties as well as external factors such as soil texture and parent material (Ndakara, 2011; Gruba and Mulder, 2015; Oyebiyi *et al.,* 2018). As a direct measure, BS has the capacity to indicate the level and degree of behaviour and the availability of crucial elements. The focus of this study is on characterising soil ECs, CEC, pH and BS under *P. gratissima, M. indica* and *T. cattapa* within Nigerian rainforest, for the purpose of providing alternative tree species capable of sustainable fertility and nutrient restoration of soil within the degraded rainforest environment. This study therefore, provided answers and accounts to the following research questions, upon which the acceptance and rejection of incorporating the EFTs into the degraded rainforest environment lies: (i) What are the levels of ECs in the soils under EFTs and Rf?; (ii) What are the levels of soil pH under EFTs and Rf?; (iii) What are the soil BSP levels under EFTs and Rf?; (iv) What are the CEC contents of the soils under EFTs and Rf?; (v) Are there differences in the amount of soil parameters between the topsoil and subsoil under the EFTs and Rf?; and (vi) Are there significant differences in soil ECs, CEC, pH and BSP under EFTs and Rf at 0.05 confidence level?

Materials and methods

Nigerian moist rainforest belt being the study area was stratified into 3 in line with the existing geopolitical units (zones) which are the south-east, south-west and south-south (Ndakara and Eyefia, 2021). The study which adopted experimental approach as a design was conducted under 3 exotic fruity trees (*P. gratissima, M. indica and T. cattapa*) using native rainforest as control for the study. The EFTs are commonly planted within the moist rainforest environment of Nigeria within settlements and farm areas, for shade and fruit production. In each zone, 5 stands of each species of the exotic fruity trees were selected in addition to 5 established rainforest control plots measuring 30 m × 30 m; making 60 sample sites from which samples were derived for the study. The exotic fruity trees selected were fully isolated without any contact with other tree canopies, while sweeping is not carried out underneath the stands. Samples of soils were got from topsoil (0-15cm) and subsoil (15cm-30cm) under the exotic fruity trees and rainforest by the use of core sampler, as adopted in studies by Ndakara (2011), Ndakara (2012), Amiolemen, Iwara, Ndakara, Deekor and Ita (2012), Ndakara (2018), Ndakara (2019), Ndakara and Ofuoku (2020), Ndakara, Eyefia and Atuma (2022). The samples were analysed in the laboratory for ECs (Ca, Mg, Na and K), pH, CEC and base saturation. In carrying out the laboratory analysis, which adopted the approach used by Ndakara (2011; 2012), the concentrations of Ca, Na and K was determined using flame photometer; Mg was determined with AAS. Determination of pH involved the electrometric method. The summation method was adopted in determining CEC, and was calculated based on the extracted soil test values converted to milliequivalents. The soil BSP was computed as percentage of the ratio of the individual milliequivalents to the total base milliequivalents. Data generated from laboratory analysis of samples were statistically analysed using descriptive and inferential techniques.

Results and discussion

Soil parameters under the exotic fruity trees and the rainforest varied. Results of studies by Ekanade (1989), Ndakara (2011; 2012; 2018; 2019),and Ndakara and Ofuoku (2020), also observed a significant variation in the parameters of soils under EFTs and the Rf; while Phil-Eze (2010), Oyebiyi *et al* (2018) and Fabricio *et al* (2018) also found variations in soil EC and CEC under tropical rainforest.

Exchangeable cations in soils under exotic fruity trees and rainforest

The ECs are among the very important plant nutrients present in soil. Reduced soil fertility when cropped for a long period of time had been attributed to nutrient exhaustion; however, their replenishment is an essential aspect of nutrients return to soil in nutrient cycling.

Table 1. Descriptive Statistics of ECs Contents in soils under EFTs and Rf.

Soil Layers	Soil Properties	Statistics	*P.gratissima*	*M. indica*	*T. cattapa*	Rainforest
Topsoil Layer	Ca2+ (mg/kg)	Mean	711.35	768.39	793.46	708.66
		SD	64.66	39.05	10.16	367.10
		CV (%)	9.09	5.08	1.28	51.80
	Mg2+ (mg/kg)	Mean	245.46	252.46	259.76	477.13
		SD	51.01	35.31	40.01	44.75
		CV (%)	20.78	13.99	15.40	9.38
	K+ (mg/kg)	Mean	56.96	60.68	61.67	115.34
		SD	5.73	4.34	5.74	26.48
		CV (%)	10.06	7.15	9.31	22.96
	Na+ (mg/kg)	Mean	46.28	53.91	54.58	87.69
		SD	6.67	4.68	6.23	16.01
		CV (%)	14.41	8.68	11.41	18.26
Subsoil Layer	Ca2+ (mg/kg)	Mean	352.57	357.58	357.39	351.46
		SD	30.48	18.58	32.26	148.46
		CV (%)	8.65	5.20	9.03	42.24
	Mg2+ (mg/kg)	Mean	90.91	101.02	100.84	194.22
		SD	16. 38	9.11	14.14	68.78
		CV (%)	18.02	9.02	14.02	35.41
	K+ (mg/kg)	Mean	17.18	15.28	18.26	27.15
		SD	2.48	2.39	3.00	10.01
		CV (%)	14.44	15.64	16.43	36.87
	Na+ (mg/kg)	Mean	19.83	18.63	20.10	28.01
		SD	3.48	2.20	3.74	3.36
		CV (%)	17.55	11.81	18.61	11.99

**SD: standard deviation; CV: coefficient of deviation.

Table 1 presents computed descriptive statistical results for the ECs Contents in soils under EFTs and Rf. The mean, SD and CV values varied in the soils under EFTs and Rf. Generally, the ECs are higher within topsoils than subsoils thus, corroborates findings reported in the research conducted by Ekanade (1989), Ndakara (2011; 2012) and Oyebiyi *et al.* (2018). However, in both soil layers, the Ca2 concentrations is highest, while Mg2, K+ and Na+ are lowest under Rf. Higher Ca2 content was reported in studies by Phil-Eze (2010), Fabio and Reinaldo (2012), Oyebiyi *et al.* (2018). The CV values showed that ECs vary among the EFTs and the Rf. While the CV values for Ca2, K+ and Na+ are higher under the Rf, the corresponding CV value for Mg is higher under the EFTs. The variation pattern shown by the ECs within topsoil is the same for Mg2, K+ and Na+ (Rf > *T. cattapa* > *M. indica* > *P. gratissima*); but different from that of Ca2 which is *T. cattapa* > *M. indica* > *P. gratissima* > Rf respectively. Within the subsoil, K+ and Na+ showed same pattern (Rf > *T. cattapa* > *P. gratissima* > *M. indica*), while Ca2 and Mg2 patterns varied. The implication of findings about the ECs contents is that the EFTs have the capacity to restore nutrient cations back to the rainforest soil. The lower concentrations of Mg2, K+, and Na2 under the EFTs could be attributed to the effect of isolation (Ndakara, 2012). Variations in the concentration of ECs within the topsoils under EFTs and the Rf is due possibly to differences and variations in the build-up of nutrient cations within the topsoil (Oyebiyi *et al,* 2018), which can be linked with differences in the biomass parameters of the different tree stands, and the return of nutrients to soil from litterfall (Ndakara, Eyefia and Atuma, 2022) and its mineralization which presumably exceeded the rate of uptake and loss through leaching (Ndakara and Ofuoku, 2020).

The group means of the ECs under the EFTs and the Rf are all lower in the subsoils than in the topsoils within the same sample sites. This could be linked with the possibility that the build-up of nutrient cations is confined to the topsoil for reasons explained earlier.

Table 2. Descriptive Statistics of the Soil CEC under EFTs and Rf.

Soil Layers	Soil Properties	Statistics	*P. gratissima*	*M. indica*	*T. cattapa*	Rf
Topsoil	CEC (meq/100g)	Mean	7.17	7.56	7.75	14.41
		SD	0.45	0.45	0.34	1.77
		CV (%)	6.28	5.95	4.39	12.28
Subsoil	CEC (meq/100g)	Mean	3.87	3.97	3.98	5.73
		SD	0.21	0.13	0.21	0.98
		CV (%)	5.43	3.28	5.28	17.10

**SD: standard deviation; CV: coefficient of deviation.

CEC of soils under exotic fruity trees and rainforest

The CEC within topsoil is higher under the Rf than under the EFTs. This is so for the reason that the Rf has the ability and capacity of higher build-up of essential nutrients within the topsoils underneath than the EFTs which are mainly isolated stands (Ndakara, 2011).

Table 2 presents computed descriptive statistical results for the soil CEC under EFTs and Rf. In both soil layers, the Rf has the highest mean, SD and CV values for CEC. This shows that soils under Rf fall within high CEC group which are > 10meq/100g, while soils under the EFTs fall within low CEC group which are < 10meq/100g (Ekanade, 1989). Soils that fall within low CEC group easily become acidic, and would frequently require liming than the high CEC counterpart (Brown and Lemon, 2016). Among the EFTs, CEC value under *T. cattapa* is highest, while CEC value under *P. gratissima* is lowest. Among the EFTs, the mean CEC values are closely similar in range. This is Perhaps due to immobilization of nutrient cations in the standing crop of the EFTs, which are isolated (Ndakara, 2011), as earlier referred to. However, the CEC of the topsoils is generally higher under the different sample sites than the subsoils. Higher nutrients within topsoils have been reported in studies by (Phil-Eze, 2010; Ndakara, 2012; Oyebiyi *et al.*, 2018; Ndakara and Ofuoku, 2020).

Table 3. Descriptive Statistics of soil B.S.P under EFTs and Rf.

Soil Layers	Soil Properties	Statistics	*P. gratissima*	*M. indica*	*T. cattapa*	Rf
Topsoil	Base saturation (%)	Mean	83.13	84.01	84.44	91.45
		SD	1.11	1.01	0.71	1.18
		CV (%)	1.33	1.20	0.84	1.29
Subsoil	Base saturation (%)	Mean	69.11	69.60	69.59	78.18
		SD	1.59	0.95	1.56	3.79
		CV (%)	2.30	1.36	2.24	4.85

**SD: standard deviation; CV: coefficient of deviation.

Base saturation percentage (BSP) of soils under EFTs and Rf

The proportion of CEC which is occupied by cations other than hydrogen (H) varies amongst the EFTs and the Rf, as well as between the two soil layers. Topsoil layer has higher B.S.P than the subsoil thus, shows that the percentage of hydrogen saturation is lower in the topsoil. BSP was higher within the soil under the Rf than that under the EFTs. Table 3 shows the percentage values of base saturations for the topsoil and subsoils under the EFTs and the Rf. The mean BS values under *P. gratissima, M. indica, T. cattapa* as well as Rf are higher in topsoil than the subsoil. Although the mean values of BSP are lower among the EFTs than the Rf, the saturation of hydrogen underneath indicates that the soils under EFTs can be very productive to support effective growth and development of essential tree crops in the Rf ecosystem. This is in line with report of findings in researches by Ekanade (1989); Marx *et al,* (1999); Fabricio *et al.* (2018). Percentage of hydrogen saturation is therefore higher under the EFTs than the Rf. However, hydrogen saturation percentages are higher in the subsoils than topsoil, which could be as a result of higher concentrations of acid in the subsoil than within the topsoil.

Soil pH under EFTs and Rf

One would expect a rise in soil pH within the topsoil as a result of build-up of exchangeable nutrient bases through nutrients return to the soil.

Table 4 shows the mean pH values of the topsoil and subsoil under EFTs and the Rf. The mean pH values revealed that there are variations in the soil pH levels underneath the EFTs and the Rf, with highest and lowest observed values in soil under Rf and *M. indica* respectively. Generally, the pH values within the subsoils are lower than those observed in the topsoils. The pH values reduced with depth mainly because base cations decreased with depth down the soil.

Table 4. Descriptive Statistics of Soil pH under EFTs and Rf.

Soil Layers	Soil Properties	Statistics	*P. gratissima*	*M. indica*	*T. cattapa*	Rf
Topsoil	Soil pH	Mean	6.14	5.51	5.79	6.26
		SD	0.53	0.43	0.37	0.69
		CV (%)	8.63	7.80	6.39	11.02
Subsoil	Soil pH	Mean	5.75	4.72	5.21	5.77
		SD	0.58	0.37	0.32	0.66
		CV (%)	10.09	7.84	6.14	11.44

**SD: standard deviation; CV: coefficient of deviation.

The pH values of topsoil indicates that the acid level of the different sample sites ranges from moderately acidic (5.2 – 6.0) to slightly acidic (6.1 – 6.5), with soils under *T. cattapa* and *M. indica* being more acidic than the soil under *P. gratissima* and the Rf respectively. The slightly acidic rainforest soil was observed in study by Marx *et al*, (1999); Fabricio *et al.* (2018). In the same vain, the pH values of the subsoil under the EFTs and the Rf ranged between moderately acidic (5.2 -6.0) to strongly acidic (= 5.1), with soil under *M. indica* being more acidic than others. While the sample sites for the EFTs comprise single tree species, the native Rf comprises many tree species as a community, which may exert different effects on the pH levels of soils under their stands. It seems that under the rainforest condition, the higher levels of base cations in the topsoil help to raise the level of soil pH. Hence the rainforest areas have relatively higher pH values as compared with the EFTs. From table 5, the F-values obtained were all greater than the critical table values except for BS in the subsoil. Therefore, apart from BS in the subsoil which is not significant, the differences and variations in the different soil variables are all significant at the 0.05 confidence level. This result is similar to reports by Brown and Lemon (2016).

However, the results of multiple comparisons (post-hoc test) of the means using the Least Square Difference (LSD) test (appendix) show that the mean differences in Ca2+, Mg2+ and K+ contents in both topsoil and subsoil are significant at the 0.05 level between the pairs of *P. gratissima* with *Rf, M. indica* with Rf and *T. cattapa* with Rf respectively. For the concentration of Na+ in the topsoil, the mean differences are significant between the pairs of *P. gratissima* with all the EFTs and Rf, M. indica with *P. gratissima* and Rf, *T. cattapa* with *P. gratissima* and Rf, and the pair of Rf with all the EFTs; while the mean differences in Na+ content in the subsoil are similar to that of the CEC in both soil layers which are significant between the pairs of *P. gratissima* with Rf, *M. indica* with Rf, *T. cattapa* with Rf, and the pair of Rf with all the EFTs respectively. The mean differences in pH values within the topsoil among the ETFs and the Rf are significant between the pairs of *P. gratissima* with *M. indica, M. indica* with *P. gratissima* and *Rf, T. cattapa* with Rf, Rf with M. *indica* and *T. cattapa*; while the corresponding pairs for the subsoil are P. gratissima with M. indica and T. cattapa, M. indica with all the EFTs and Rf, *T. cattapa* with all the EFTs and Rf, Rf with *M. indica* and *T. cattapa* respectively.

Table 5. ANOVA Results for the Differences in Soil Properties under EFTs and Rf.

Soil Layer	Soil parameters	Groups	Sum of squares	d/f	Mean square	F-values	Table F	Remarks
Topsoil	K+	Between	35882.983	3	11960.994	60.07	2.84	Significant
		Within	11150.000	56	199.107			
		Total	47032.983	59				
	Ca2+	Between	10225671	3	3408556.91	95.94	2.84	Significant
		Within	1989504	56	35526.862			
		Total	12215175	59				
	Mg2+	Between	564774.3	3	188258.106	99.60	2.84	Significant
		Within	105843.3	56	1890.060			
		Total	670617.7	59				
	Na+	Between	15088.450	3	5029.483	55.46	2.84	Significant
		Within	5078.133	56	90.681			
		Total	20166.583	59				
	CEC	Between	541.247	3	180.416	196.78	2.84	Significant
		Within	51.342	56	0.917			
		Total	592.589	59				
	BSP	Between	73.333	53	1.384	4.981	2.84	Significant
		Within	1.667	6	0.278			
		Total	75.000	59				
	pH	Between	4.716	3	1.572	6.039	2.84	Significant
		Within	14.580	56	0.260			
		Total	19.296	59				
Subsoil	K+	Between	1522.200	3	507.400	14.284	2.84	Significant
		Within	1989.200	56	35.521			
		Total	3511.400	59				
	Ca2+	Between	374673.6	3	124891.217	19.973	2.84	Significant
		Within	350176.0	56	6253.143			
		Total	724849.6	59				
	Mg2+	Between	107435.4	3	35811.794	26.323	2.84	Significant
		Within	76185.867	56	1360.462			
		Total	183621.3	59				
	Na+	Between	836.400	3	278.800	25.623	2.84	Significant
		Within	609.333	56	10.881			
		Total	1445.733	59				
	CEC	Between	36.133	3	12.044	45.254	2.84	Significant
		Within	14.904	56	0.266			
		Total	51.037	59				
	BSP	Between	63.833	46	1.388	1.616	2.84	Not Significant
		Within	11.167	13	0.859			
		Total	75.000	59				
	pH	Between	11.275	3	3.758	15.531	2.84	Significant
		Within	13.552	56	0.242			
		Total	24.827	59				

Significant at F > critical table F (2.84) at the 0.05 level.

These results therefore showed that the different EFTs and the Rf do not have the same nutrient compositions in both the topsoil and subsoil layers respectively under their stands (Ekanade, 1989). Although the concentrations and amount of some soil properties such as Ca2+, Mg2+, K+, C.E.C and soil pH have close similarities under both the EFTs and the Rf.

This is clearly because the different sample sites are made of different tree species; while the species of the EFTs are not contained in the Rf; and the EFTs have peculiar crown architectures which differ from that of the Rf trees.

Conclusion

Soil elements varied under the exotic fruity trees (EFTs) and the rainforest (Rf). The pattern of variation shown by the ECs within the topsoil is the same for magnesium (Mg2+), potassium (K+) and sodium (Na+); but differ from that of calcium (Ca2+). Within the subsoil, K+ and Na+ showed similar pattern, while Ca2+ and Mg2+ patterns differed. The differences in soil variables under EFTs and the Rf were significant at the 0.05 confidence level. The CEC under EFTs are < 10meq/100g, while that of the Rf is > 10meq/100g. The EFTs have the capacity to restore nutrient cations back to the rainforest soil, with frequent liming thus, the EFTs can be used to restore nutrients to the soil. The saturation of hydrogen under EFTs indicates that soils underneath can be productive to support effective growth and development of tree crops in the Rf environment. Therefore, the EFTs can be grown in the rainforest environment for sustainable nutrient restoration in the degraded rainforest environment.

References

Amiolemen SO, Iwara AI, Ndakara OE, Deekor TN, Ita AE. 2012. Assessment of the Nutrient Status of Soil *under Chromolaena odorata L.* (Siam Weed) Fallow in Moniya, Oyo State, South-Western Nigeria. Ethiopia Journal of Environmental Studies and Management **5,** p 252-259.

Brown K, Lemon J. 2016. Fact Sheets Cations and Cation Exchange Capacity. Retrieved from: https://www.soilquality.org.au/factsheets/cation-exchange-capacity

Crouse D. 2015. Soils and Plant Nutrients Extension Gardener Handbook Retrieved from: https://content.ces.ncsu.edu/extension-gardener-handbook/1-soils-and-plant-nutrients.

Ekanade O. 1989. The effects of productive and non-productive kola, *Cola nitida* vent. (Schott and Endlicher), on the status of major soil physical and chemical properties in South-Western Nigeria. The International Tree Crops Journal **5,** p 279-294.

Fabio A, Reinaldo L. 2012. Evaluation of Cation Exchange Capacity (CEC) in Tropical Soils Using Four Different Analytical Methods. Journal of Agricultural Science **4,** p 278-289.

Fabricio TR, Eliana FGCD, Oscarlina LDSW, Daniel CB, José HCJ. 2018. Soil organic matter doubles the cation exchange capacity of tropical soil under no-till farming in Brazil. Journal of the Science of Food and Agriculture. http://dx.doi.org/.org/10.1002/jsfa.8881

Gałka M, Szal M, Watson EJ, Gallego-Sala A, Amesbury MJ, Charman DJ, Roland T, Turner TE, Swindles GT. 2017. Vegetation succession, carbon accumulation and hydrological change in sub-Arctic peatlands (Abisko, northern Sweden). Permafrost Periglac.. http://dx.doi.org/10.1002/pp.1945.5

Gałka M, Tobolski K, Górska A, Lamentowicz M. 2017. Resilience of plant and testate amoeba communities after climatic and anthropogenic disturbances in a Baltic bog in northern Poland: implications for ecological restoration. The Holocene, **27,** p 130–141.

Gruba P, Mulder J. 2015. Tree species affect cation exchange capacity (CEC) and cation binding properties of organic matter in acid forest soil. Science of the total Environment **511,** p 655-662.

Gruba P, Mulder J, Brozek S. 2013. Modelling the pH dependency of dissolved calcium and aluminium in O. A. and B horizons of acid forest soils. Geoderma, **206,** 85-91.

Kardol P, Throop HL, Adkins J, De Graaff M. 2016. A hierarchical framework for studying the role of biodiversity in soil food web processes and ecosystem services, Soil Biology and Biochemistry, **102,** p33-36. http://dx.doi.org/10.1016/j.soilbio.2016.05.002

Kharel G, Sacko O. Feng X, Morris JR, Phillips CL, Trippe K, Kumar S, Lee JW. 2019. Biochar Surface Oxygenation by Ozonization for Super High Cation Exchange Capacity. ACS Sustainable Chem. Eng. **7,** p 16410–16418.

Marx ES, Hart J, Stevens RG. 1999. Soil Interpretation Guide, E. C. 1478 (Oregon state university extension service).

Komprdová K, Komprda J, Menšík L, Vaňková L, Kulhavy J, Nizzetto L. 2016. The influence of tree species composition on the storage and mobility of semivolatile organic compounds in forest soils. Science of the Total Environment **553,** p 532-540. http://dx.doi.org/10.1016/j.scitotenv.2016.02.132

Mori AS, Isbell F, Fujii S, Makoto K, Matsuoka S, Osono T. 2016. Low multifunctional redundancy of soil fungal diversity at multiple scales. Ecology Letters 249-259. https://doi.org/10.1111/ele.12560

Mueller DN, Gerber SJ, Johnston M, Ray KD, Ramankutty N, Foley AJ. 2012. Closing yield gaps through nutrient and water management. Nature, **490**, p 254-257.

Ndakara OE. 2011. Litterfall and Nutrient Returns in Isolated Stands of *Persea gratissima* (Avocado Pear) in the Rainforest Zone of Southern Nigeria. Ethiopia Journal of Environmental Studies and Management **4,** p 42-50.

Ndakara OE. 2012. Litterfall and Nutrient Returns in Isolated Stands of *Terminalia catappa* Trees in the Rainforest area of Southern Nigeria. Ethiopia Journal of Environmental Studies and Management **5,** p 1-10.

Ndakara OE. 2018. Assessment of Litterfall nutrient flux in isolated stands of Mangifera indica in Orogun rainforest region, Southern Nigeria. Sokoto Journal of The Social Sciences **8**, p 176-186.

Ndakara OE. 2019. Influence of exotic trees on physical properties of soil in tropical rainforest: Implications for environmental management in Southern Nigeria. Sahel Analyst Journal of Management Sciences **17,** p 71-88.

Ndakara OE, Eyefia OA. 2021. Spatial and Seasonal Variations in Rainfall and Temperature across Nigeria., Journal of Biodiversity and Environmental Sciences (JBES) **18,** p 79-92. Https://innspub.net/jbes/spatial-and-seasonal-variations-in-rainfall-and-temperature-across-nigeria/

Ndakara OE, Ofuoku UA. 2020. Characterizing plant biomass and soil parameters under exotic trees within rainforest environment in southern Nigeria. AIMS Environmental Science **7,** p 611-626.

Ndakara OE, Eyefia OA, Atuma IM. 2022. Litterfall nutrients and the soil nutrients under three indigenous tree species in the Nigerian rainforest region. International Journal of Biosciences **20,** p 37-44.

Oyebiyi OO, Ojetade JO, Muda SA, Amusan AA. 2018. Comparative study of three methods of determining cation exchange capacity of three major soils in the rainforest region of Southwestern Nigeria. Communications in soil science and plant analysis, **49,** p 2338-2344.

Pawlik JR, Burkepile DE, Thurber RV. 2016. A Vicious Circle? Altered Carbon and Nutrient Cycling May Explain the Low Resilience of Caribbean Coral Reefs. BioScience **66,** 470–476.

Phil-Eze O. 2010. Variability of soil properties related to vegetation cover in a tropical rainforest landscape. Journal of Geography and Regional Planning **3,** p 177-184.

Pincus LN, Ryan PC, Huertas FJ, Alvarado GE. 2017. The influence of soil age and regional climate on clay mineralogy and cation exchange capacity of moist tropical soils: A case study from Late Quaternary chronosequences in Costa Rica. Geoderma **308,** p 130-148.

Suzuki KF, Kobayashi Y, Seidl R, Senf C, Tatsumi S, Koide D, Azuma WA, Higa M, Koyanagi TF, Qian S, Kusano Y, Matsubayashi R, Mori AS. 2021. The potential role of an alien tree species in supporting forest restoration: Lessons from Shiretoko National Park, Japan, Forest Ecology and Management. http://dx.doi.org/10.1016/j.foreco.2021.119253.493,(119253)