SITE INDEX ANALYSIS OF AN AGE SEQUENCE OF *GMELINA ARBOREA* PLANTATION IN JALINGO, TARABA STATE, NIGERIA

***Yani J.P; [2] Tella, O.I; [3]David D.L and [3]Ali, B.D**
[*]Forestry Section Ardo-Kola Local Government Area, Taraba State-Nigeria
[2]Department of Forestry and Wildlife Management, Modibbo Adama University of Technology, Yola-Nigeria
[3]Department of Biological Sciences, Adamawa State University, P.M.B. 25, Mubi-Nigreria
E-mail: lammababs@yahoo.com

ABSTRACT

Site index is a useful concept in analyzing plantation forestry. Among the numerous environmental factors affecting tree growth, the important relationship between soil and tree growth is most apparent. This is because evaluation of the site from soil characteristics has several advantages. Site index is essential in quantifying sites. A research was conducted to study site index of an age sequence of *Gmelina arborea* plantation. The parameters evaluated included soil and size characterization of the vegetation that affect tree growth into a unified classification and to quantify site of the plantations. The chemical properties of soils in the plantation revealed that soil pH was slightly acidic to alkaline as the soil depth decreases. There was a significant difference in terms of soil particle size distribution in the plantation at ($P \geq 0.05$ or $P \geq 0.01$). The percentage content of sandy, clay and silt soils was highest in sandy soil (63.13%) while the lowest was recorded in silt (18.31%). Site index equation with good fit from environmental factors selected for site investigation was formal using a multiple regression analysis of four functional forms namely- linear, semi-log, exponential and double-log, respectively. In conclusion, analysis using semi-log regression model seems to yield better in this type of plantation and the soil characteristics were significantly related to growth, although not the same everywhere.
Key word: Site index, age sequence, plantation, *Gmelina arborea*.

INTRODUCTION

Fast-growing trees are increasingly being cultivated in West Africa for use in pulp and paper industries and *Gmelina arborea* is among the tropical timber species most often evaluated for this purpose because of its exceptional productivity with rapid and sustained growth with 8 to 12 years rotational period (1, 2). An estimated yield in excess of $30m^3$ timber ha^{-1} $year^{-1}$ can be achieved in fertile soil of rainforest in Nigeria. Today, *Gmelina* plantations in Nigeria are estimated at about 122,000ha (3). Therefore, in order to enhance *Gmelina* production to achieve a desirable goal, survey of the plantation sites and classification are necessary in forest management. However, due to non completion of some of the pulp and paper industries in Nigeria as well as the poor performance of other industries, considerable percentages (over 70%) of the *Gmelina* pulpwood plantations in Nigeria exceeded the rotation age for pulp and as such are no longer suitable for pulp and paper production. However, acceptable yields are not always realized under plantation-style management, because productivity of *Gmelina arborea* appears closely related to soil fertility. Czamowski and Humphreys (4) examined dominant site factors for planted *Pinus radiate* across a range of geographical regions. They derived a complex equation defining site index as a function of humidity, soil cations, mean soil particles and foliar indirectly soil levels phosphorus. They considered that their equation embraced the essential and most dominant characteristics determining site index, with complexity of the functions reflecting the factors controlling site index. However, this complex approach has not been extended into forest management and yield prediction.

Soil profile descriptions alone can be a useful basis for defining and predicting site, particularly in an area of diverse soil (5). The growth of plantation trees is often observed to vary with changes in the soil profile. In Queensland, Van Altena (6) and Pegg (7) used soil physical and hydrological characteristics and soil colour to classify sites for *Pinus elhoott* and *P. caribaea* plantations. Turvey (8) showed in Gippsland Victoria, those soil map units based on soil profile criteria are strong indicators of significant differences in stand volume production at age 10. Site index analysis is a useful concept in plantation forestry where it is used to delineate areas of different productivity. The factors which have the greatest bearing in a region are used in the delineation. As these factors may vary from region to region, the variable used to define a site may also vary between regions.This study was conducted to assess site index analysis of an age sequence of *Gmelina arborea*.

MATERIALS AND METHODS

Study area

The study was carried out at College of Agriculture *Gmelina arborea* plantation located in Jalingo, Taraba State. The area lies within latitude $9^0$00N-$9^0$30N and longitude $11^0$00E-$12^0$00E (9). The climate comprises of two distinct seasons. The rainy season which spans from the months of April and October and the dry season is between November and March. An average rainfall of 1250mm is experienced annually with the peak period occurring between the months of July and August. The temperature ranges between 30^0C and 40^0C concise with months preceding the rain, while an average of low temperature of 10^0C is recorded at peak harmattan (10).

Collection of Samples

The soil samples were collected at 4 depth levels; these are 0-15cm, 15-30cm and 60-90cm (10)). 100m x 100m was mapped out of the 8 hectares of an age sequence of *Gmelina arborea* plantations ranging 33, 32, 31, 30, 29, 28, 27, 22 and 20 age variations respectively. In each of the earmarked plot (1 hectare), 3 sample plots were randomly located and each plot measuring 25m x25m (0.0625 ha) was selected based on the number of tree stand per plot. Soil were then collected in 3 replications from identified three spots in the sum sample plots with equal distances from the centre spot to the two other spots, with soil anger (11).

Soil Analysis

Soil samples collected were sieved using a size of 2mm sieve and air dried. The particle size distributions of the soils were determined by Bouyoucos-hydrometer method. Soil pH was determined using a pH water Jenway 3015 meter at soil water of 1:2 after standardizing the pH meter at buffer as described by Jaiswal (12). Organic matters were determined using Walkley and Black (13), while available phosphorus was determined using Bray method.

Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{2+} and K^{+}) were determined by EDTA titremeatry method using EBT and mureoxide indicator, while Na^{2+} and K^{+} were determined by flame photometer; available phosphorus was determined using Bray method as described by Loganathan (14) and Nitrogen was determine by digestion using conc. H_2So_4 with Kheldah tablet as described by Agbenin (15).

Measurements of Trees (height, girth, diameter at breast height (DBH)

Dominant mean trees were located and grouped into Basal area (B_A) classes. The Basal area (B_A) was determined by converting to diameter all the measurements of trees girth (g) in the relation:

D= 8/h

$$B_A = \frac{\pi d^2}{4}$$

Where g = girth (m)
D = diameter (m)
B_A = Basal area (m^2)
π = Mathematical constant (Pi) =3.142

The mean Basal area (B_A) for the classes were computed and the values whose Basal area (B_A) was the closest to the class values were located in each class (Warren, 2011). Meanwhile, the mean height (H) of the trees in an age sequence of *Gmelina* plantation was determined using Haga altimeter.

Data Analysis Techniques for the Site Index Equation

Descriptive statistics was employed in describing the site index characteristics of the plantations. Multiple regression models were also used to evaluate the measurements of the site factors relationship.

A common approach employed to set up equation is presented as:

$H=b_0+ b_1 \times \chi_1 (A) + b_2 \times \chi_2 + b_3 \times \chi_{3......}+ b_n \times \chi N_n$ equation ………………1.

Where H=height
A=age

χ_1, χ_2, χ_3 represent soil or other environmental factors (eg. aspect, slope, elevation, photoperiod, air temperature, thickness of the A horizon, depth to a fine-textured horizon i.e. any climatic or topographic factors), $b_0 ....b_n$-1 are constant to be solved by least squares.

If the standard for site index (normally, 20, 25, 50 years) is substituted for A, then the equation becomes a site index equation.

Log SI= $b_1 + b_2 \times B\ b_3 \times C + b_4 \times D......+ b_n-1 \times N$ equation 2

Where SI denotes site indexes, i.e. height at standard age; $b_0 + b_1$ (1/A) is a constant because age is now constant (16). The implicit form of equation for the model is given by: SI = $b_0 (\chi_1 \times \chi_2 \times \chi_3 \times \chi_4 \times \chi_5, U_1)$.

Linear, exponential, semi-log and double-log form of regression were best fitted for these kinds of data. Where:

SI denotes the height (h) and is regarded as independent variable.

χ_1, χ_2, χ_3, χ_4, χ_5 denotes environmental factors as soil characteristics, girth of trees (Dbh) are regarded as dependent variables. Here, semi-log model gave a best fit description of the site factors of the *Gmelina* plantation and was chosen as the lead equation on the basis of the number of significant variables magnitude of the adjusted R^2, F- statistics standard error and sign (±) of the coefficient. The explicit form of the lead equation is given as:

$SI = \log b_0 + \log b_1 \times \chi_1 + \log b_2 \times \chi_2 \ldots\ldots + \log b_n - 1 \times \chi_n + U_1$

Where SI = denote site index i.e. height (H)

Y = Height of the dominant trees (M)

χ_1 = Diameters of dominant trees at breast height (cm)

χ_2 = Soils pH (H_2O)

χ_3 = Soil organic matter (OM) (%)

χ_4 = Nitrogen (%)

χ_5 = Available phosphorus (Mg/kg^{-1})

χ_6 = Magnesium (Mg^+) C.M.O/(+) Kg

χ_7 = Calcium (Ca) C.M.O/(+) Kg

χ_8 = Sodium (Na) C.M.O/(+) Kg

χ_9 = Hydrogen ions (H^+) C.M.O/(+) Kg

χ_{10} = Aluminum ions ($Al3^+$)

χ_{11} = Potassium (K) Mg/Kg

χ_{12} = Copper (Cu) Mg/Kg

χ_{13} = Iron (Fe) Mg/Kg

χ_{14} = Zinc (Zn) Mg/Kg

RESULTS AND DISCUSSION

Table 1 that there is a significant difference in the site factors in relation to site index, which involves measurements of soil characteristics, girths, diameter at breast height (Dbh) as dependent variables and tree height as independent variable.

Table 1: Parameter estimate of chemical properties of soils obtained from an age sequence of *Gmelina arborea* plantation.

Soil parameter	Regression Coefficient	Prob. > (T)
Constant	81.3729**	0.9166
DBH (χ1)	9.562911**	0.0832*
Soil pH (χ2)	43.353711**	0.0472*
Organic matter (χ3)	-5.568067**	0.0385**
Nitrogen (χ4)	0.760341**	0.0567*
Phosphorus (χ5)	20.754859**	0.0546*
Magnesium (χ6)	33.326682	0.4969^{NS}
Calcium (χ7)	40.155662	0.4997^{NS}
Sodium (χ8)	53.896824	0.7122^{NS}
Hydrogen (χ9)	-17.12494**	0.0446*
Aluminum (χ10)	67.391371	0.1058^{NS}
Potassium (χ11)	17.01137	0.8003^{NS}
Copper (χ12)	-38.221129	0.2804^{NS}

Iron (χ13)	-74.495814**	0.0293**
Zinc (χ14)	12.428132**	0.0145**
R^2	0.6863	
F – value	0.425	
Root MSE	120.61848	

** Significant at 1% ($P \leq 0.01$) ** Significant at 5% ($P \leq 0.05$)

The study also shows that, soil pH, organic matter, available phosphorus and nitrogen at ($P\geq 0.05$) were statistically significant to the plantation. Although they are low in content pH (6.36 and 7.33), the increase of pH with depth could be attributed partly due to the leaching of exchangeable cations with percolating water or its uptake by plants and thus low pH values at the top and high values at the subsoil.

Organic matter, total nitrogen and available phosphorus content of the soils showed that the soils are low in these elements, though their contents are higher on the surface than the subsoil. The low organic matter could not be unconnected with sparse vegetation. However, Oseni *et al.* (11) reported that other factors such as parent material, clay content, temperature, rainfall distribution usually have modifying influence on soil organic matter content.

While exchangeable cations have played little or no significant role in their presence in the soil which was generally; low magnesium ($P\leq 0.4969$), sodium (0.30-0.33), calcium ($P\leq 0.49969$), hence, have no significant difference ($P\leq 0.05$) in the growth and development of the plantation. The elements increase with depth due to their leaching with percolating water, hence having relative values at the subsoil than topsoil (16).

Site factors analysis showed that the region coefficient of organic matter (OM), sodium (Na) and potassium (K) carried a negative sign (-), though violate some assumptions consistent with a priority expectation that a decrease in organic matter and other negative coefficient elements would have a positive effect on the growth and development especially height of trees in the plantation (Table 2).

The equations of the multiple regression analysis of the four functional forms show that, the best fit for the evaluation of the site index (Y) analysis which best described the *Gmelina arborea* plantation is the semi-log regression model, which seems to yield better. The equation: $Y = 81.37 + 91.5\chi_1 + 43.3\ \chi_2 + \ldots\ldots\ldots\ldots + b_{10}\ \chi_{10} + U$, have shown that the ordinary least square (OLS) combinations of values of the parameter estimates b_0, b_1, b_2, b_3, $b_4\ldots\ldots b_n$ have higher levels of influence on the height (Y) of trees in the plantations generally mapped out of 8 hectares of an age sequence of *Gmelina arborea* plantation, when semi-log regression model is used. The result in double-log model revealed that, not all variables contributed fully to the growth of the plantation. This may be due to poor management of the plantation and other factors such as incidence of the fire outbreak, encroachment of herdsmen and their cows into the plantation as well as other diseases. The coefficient of multiple regression model of the particle size distribution of the soil revealed a number of statistically significant of the parameters, which vary among the functional forms namely;

linear, semi-log, exponential and double-log. Clay and silt soils were statistically significant at (P≥ 0.05) in supporting trees development and to enhance pulpwood production. Clay level of significant with f value 0.5 and adjusted R^2 0.446 while silt (P≥0.05) level of significant with f- value 0.446 and adjusted R^2 0.613 respectively.

Table 2: Estimated Parameters for Site Index of *Gmelina aborea*

Variable	Linear	Semi-log	Exponential	Double-log
Intercept	229.734775***	81.372911	3.488575***	3.196530
	(261.167858)	(744.202943)	(1.19969108)	(3.36003730)
DBH (χ1)	-0.63208	9.562911**	-0.007699	-0.138918
	(1.745697)	(64.8464416)	(0.00744857)	(0.28143327)
pH (χ2)	-25.626961**	43.353711**	-0.058537**	0.421354**
	(34.559283)	(334.0974869)	(0.14745805)	(1.44998160)
Organic matter (χ3)	9.765587***	-5.568067**	0.010644**	0.052156**
	(28.083793)	(27.199485)	(0.11982834)	(0.11804564)
Nitrogen (χ4)	85.741950**	0.760341**	1.203802**	0.142659
	(231.7053141)	(45.284492)	(0.98864358)	(0.19653449)
Available Phosphorus (χ5)	2.649718**	20.754859**	0.024125**	0.138377
	(8.6033152)	(79.3894922)	(0.03670875)	(0.34455004)
Magnesium (χ6)	25.224289	33.326682	0.106510**	0.116509**
	(17.07530640)	(48.766009)	(0.07285716)	(0.21164426)
Calcium (χ7)	-5.201239	40.155662	-0.018138	0.205740
	(11.29329260)	(59.156155)	(0.04818638)	(0.25673745)
Sodium (χ8)	-3.581629**	53.896824	-0.012463	0.199670
	(4.87572496)	(145.43010765	(0.02080381)	(0.63116602)
Hydrogen (χ9)	18.361774	-17.12494**	-0.100558	-0.164333
	(19.48194746)	(52.32896244)	(0.08312385)	(0.22710746)
Aluminum (χ10)	20.869269	67.391371	0.043928	0.227263
	(24.02750508)	(41.39788178)	(0.10252091)	(0.17966662)
Potassium (χ11)	13.659804**	17.01137	-0.126881**	0.007395
	(160.016384)	(66.94069348)	(0.68276022)	(029052231)
Copper (χ12)	-1.697641	-38.221129	-0.007092**	-0.148016
	(1.37049348)	(35.10317935)	(0.00584764)	(0.15234764)
Iron (χ13)	-2.221342**	-74.495814***	-0.007646	-0.272509
	(1.20101671)	(61.36085538)	(0.00512452)	(0.26630584)
Zinc (χ14)	1.604012**	12.428132***	0.106206***	0.177601**
	(15.36576121)	(52.76062549)	(0.0656285)	(0.22898088)
F – value	0.612	0.425	0.791	0.574
Adjusted R^2	0.8447	0.8167	0.7235	0.4839

The values given in parenthesis indicate standard errors.
*Significant at 5% (P ≤ 0.05) ** Significant at 1% (P ≤0.01)

Linear regression model seems to yield better in terms of signs (±) and magnitude of coefficient. These have influence in organic matter, retention in the soil, hence better nutrient supplies to the plantation.

Table 3: Estimate parameter of particle size distribution obtained from an age sequence of *Gmelina aborea* plantation soil.

Soil parameter	Regression Coefficient	Average percentage	Prob. < (T)
Constant	-4040.5		0.8147
Sandy	41.22994NS	63.13%	0.8111^{NS}
Clay	39.6547**	18.56%	0.0179**
Silt	40.1453**	18.31%	0.0559*
R2	0.8124		
F-ration	0.521		
Root MSE	126.23821		

** = Significant at 1% * = Significant at 5% NS = Not significant

In Table 3 above, sandy soil shows no significant difference in term of size (P≥ 0.131), hence poor water and nutrient retention. The percentage content of the soil types also revealed that, sandy soil had the highest 63.13%, clay soil followed by clay 18.56%, and the lowest was recorded silt soil with 18.31%. This indicates that sandy soil usually dominate artificial forest soil and this does not support nutrient retention for man-made forest plantation to utilize and the plantation can easily be prone to erosion as reported by Oseni *et al*. (11).

CONCLUSION

The result revealed that some elements such as magnesium, calcium, aluminum, copper have little or no significant influence in the growth and development of the plantation, while elements like nitrogen available, phosphorus, soil pH, organic matter, Iron, even though are low in content yet played a significant role in the development of the plantation. Clay and silt soils had a significant impact on nutrient retention and supplies to the plant with 18.56% and 18.32% respectively. Sandy soil with highest percentage of 63.13% had poor nutrient capacity, hence does not support nutrient supplied. Site index is a useful concept in analyzing plantation forestry. Of the numerous environmental factors affecting tree growth, the important relationship between soil and growth is most apparent. In this study however, the soil characteristics are significantly related to growth, although not the same everywhere. This is because evaluation of the site from soil characteristics has several advantages. Semi-log equation with good fit was developed for this type of plantation as site index equation.

ACKNOWLEDGEMENTS

The authors are most grateful to Mr. Benneth O. Anokwu Head of Department Forestry, Taraba State College of Agriculture Jalingo and his entire staff for given the approval to conduct the research in the College Forest Plantation.

REFERENCES

1. Greaves, A. (1981). *Gmelina arborea*. *For. Abstr*. 42:237-258.

2. Twimasi, K.A. (1991). Strength Characteristics of Packaging Paper Made from Tropic Wood Species. *Tropic Sci.* 31:95-100.

3. Onyekwelu, J. C. (2001). Growth Characteristics and Management Scenarios for plantation grown *Gmelina arborea* and *Nauclea diderrichii* in South West Nigeria: *Munich Hieronymus Verlag*., 196P.

4. Czamowski, N.S. and Humphreys, N.J. (1986). *Ekologial Polska* 19.

5. Turvey, N.D. (2009). Site Index Prediction of *Eucalyptus* Durnil Maiden using Soil and Site Parameters. *Austr. Forestry*, 73: 4.

6. Van Altena, A.C. (2007). Growth Comparison of Slash Pine and Honduras Caribbean Pine at Toolara Q'id For. Dept. *Res. Note*. No. 28.

7. Pegg, R.E. (2009). Assessment of Groundcover Monitoring Sites in South Australia: Survey Programme for Soil (Wind/water) Erosion Hard. Southeast Queensland. Q'ld Dept. *Forest Res. Note* No. 19.

8. Turvey, N.D. (2010). The Relationshionship among soil parameters, tree nutrition and site index in a forest systems. *Austr. For*. 19(1): 77-88.

9. NAASOES (1980). College of Agriculture Jalingo Master Plan; NOVA ARCH ASSOCIATES Omni Environmental Services: Architects, Planner & Construction management Consultants.

10. Formecu (1997). Forestry Management Evaluation and Co-ordinating Unit: Focuses on Forestry Resources Preservation and Prevention of Desertification.

11. Oseni, O. A., Ekperigin, M. M., Akindahunsi A. A. and Oboh, G. (2007). Studies of physicochemical and Microbial Properties of Soils from Rainforest and Plantation in Ondo State, Nigeria. *African Journal of Agricultural Research,* 2: 605 – 609.

12. Jaiswal, P. C. (2004). *Soil, Plant and Water Analysis*. Allahabad Agricultural Institute: Deemed University Allahabad, 211007. Kalyain Publisher New – Delhi, India.

13. Walkley, A. and Black, I.A. (1934). An Examination of the Degfgref Method for Determining Soil Organic Matter and a Proposed Modification of Chronic acid titration method. *Soil Sci.,* 31:29-38.

14. Loganathan, P. (1992). *A Laboratory manual of soil and plant analysis*. Department of Soil Science, University of Science and Technology Port Harcourt, Nigeria.

15. Agbenin, J. O. (1995). *Laboratory Manual for Soil and Plant Analysis Selected Methods and Data Analysis,* Faculty of Agriculture/Institute for Agricultural Research Department of Soil Science Ahmadu Bello University Zaria, Published by the Author.

16. Brack, C.L. (2001). Forest Measurements and Modeling: Measuring Trees, Stand and Forest for Effective Forest Management. ISBN. 0731524136. Computed Based Resources.

17. Zata, A. I., Usman B.H., Vahyada, E.I. Duda, Y. Mord Nwaka, G.I.C. (2002). Profile Nutrient Distribution and Fertility Potential of an Entisoil of North Eastern Nigeria: *Nigeria Journal of Education and Technology*, 3(112): 26-32.