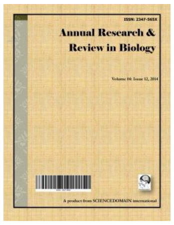

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Soil Properties and Site Index in an Age Sequence of *Gmelina arborea* in Jalingo Taraba State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author DLD designed the study, wrote the protocol and interpreted the data. Author JPY anchored the field study and gathered the initial data. Author JAW performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Soil potential productivity and the site index in an age *Gmelina arborea* plantation in Jalingo forest plantation were studied. The plantations which were of different age variations, were mapped out into eight compartments with a measurement of 100 m x 100 m. For each of the compartment 16 plots were unmarked, 25 m x 25 m (0.0625 ha) out of which three plots was randomly selected as sampled plots. In each of the sampled plots, site factors were measured. In identifying mean trees, all the stems in each plot were distributed into basal area classes range as 15- 50 cm, 55-85 cm and 86-121 cm tagged A, B and C respectively. The soil samples were assessed in the laboratory for the physical and chemical properties. The results showed that soils in the Gmelina plantation are generally slightly acidic; and acidity increases with increase in the soil depth. For the height of *Gmelina arborea* plantation, the results showed that not all variables contributed fully to the growth and development of the trees height. Semi-log regression model seems to yield better of the equations.

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1. INTRODUCTION

Gmelina arborea (Roxb) is a native from Pakistan South to Srilanka and East to Myanmar, Thailand, Vietnam and Southern China. It is extensively planted as a fast-growing tree in tropical areas of Africa, Asia, Australia and America [1]. In Africa, a total area of Gmelina plantation has been estimated at 130,000 ha [2]. Large scale plantations are found in Senegal, Mali, Gambia, Sierra-Leone, Cote d'ivoire, Burkina Faso, Ghana, Nigeria, Cameroon and Malawi [2]. *Gmelina arborea* is moderately sized to large deciduous tree with a straight trunk, smooth bark or scaly, corky, grey to yellowish grey, leaves simple, stipules absent, petiole 5-15cm long, short hairy or glabrous blade heart-shaped [3].

It tolerates a wide range of environmental conditions, but grows best where there is extremes of temperature and mean annual rainfall of 18-25°C and 1778 mm - 2286 mm respectively, and where there is a distinct dry season in which atmospheric humidity is not below 40% [4]. Although Gmelina can be found on a variety of soils, it prefers deep moist soils with ample supply of nutrients. In plantations they require a well-drained fertile soil and do not stand waterlogged sites. Gmelina is an opportunist species in rainforest and has been classified as a long-lived pioneer and has a high light requirement [5].

In Nigeria Gmelina is among the leading plantation tree species. Timber production appears to be the most favoured alternative. Gmelina wood is appropriate for furniture and light construction [6].

The measurements of site factors in an age sequence *Gmelina arborea* plantation in Jalingo, revealed numerous environmental factors affecting tree growth. Meanwhile, the soil characteristics significantly related to growth of Gmelina are not the same anywhere. Relative wetness, sandiness, depth, amount of clay in the A and B horizons, nutrient levels, soil temperature etc. have different proportionate effects depending on the kind of soil Gmelina is grown [7].

Unfortunately, it is difficult to establish for a particular plantation the most important soil characteristics affecting growth. For this reason, the use of soil characteristics as index of productivity has limitations. Hence soil and site index investigation usually consist of multiple regression using height (H) as the dependent variable and number of soils and other environmental characteristics as the independent variables. The aim of this model is to enable the management to forecast the productive capabilities of planted stands and evaluation of land for good growing. This provides a model for site quality in order to rate productivity. This however, will suggest good prospect for improvement programmes that will sustain the existing plantations especially in Nigeria. Hence, the study was designed to identify variables such as physical and chemical properties of the soil, tree height (h), girth etc. to develop multiple regression models.

2. MATERIALS AND METHODS

2.1 The Study Area

The study was carried out in the College of Agriculture *Gmelina arborea* plantation, Jalingo, Taraba State. The plantation is situated between latitude 9°00' N and 9°30' N and longitude 11°00' E and 12°00' E. An average annual rainfall of 1250 mm is experienced. The highest temperatures ranging between 30°C and 40°C coincide with the months preceding the rains, while an average low temperature of 10°C is recorded at the peak of harmattan- a cold-dry, dusty trade wind in the sub-region of West Africa [8]. The vegetation of the site consists of open savannah wood-land with tall grasses. There is a scattered distribution of short broad leaved trees with deep tap root. These are of deciduous stock [9].

2.2 Soil Sampling and Collection

The soils were sampled at the *Gmelina arborea* plantation, Jalingo, Taraba state. The sampled soils were collected at four depths (cm) levels (0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm) respectively. 8 hectare of an aged sequence of (32, 31, 30, 29, 28 and 19 age stands) *Gmelina arborea* plantation were mapped out in 100 m x 100 m and each of the hectare was divided into 16 plots of 25 m x 25 m (0.0625 ha). Each of the three (3) plots was randomly selected and was made up of 33.33% sampling intensity. In this way twenty four (24) sample plots were selected. The centre of each sampled plot was located and soils were dug out, and packed at a respective depth (cm) levels; this is done to enhance better soil laboratory assessments.

2.3 Measurements of Trees' Height Using Hagar Altimeter

The height (h) of trees was measured using Hagar Altimeter.

The readings taken (top and base) the tree height was calculated using the formula:

$$h = \frac{d \times t}{r}$$

Where

h = height of the tree
d = horizontal distance from the base to the observer.
t = total readings of both tree top and base added together.
r = range selected.

In a situation where the distance of the reader from the base is equal to the selected range then, the difference between the top and bottom readings will give the height of the tree [10].

2.4 Measurements of Mean Dominant Trees (Girth) and Diameter at Breast Height

In measuring the mean trees, all the stems in each plot were distributed into basal area classes range as 15 – 50 cm, 55 – 85 cm and 86 – 121 cm tagged A, B and C respectively.

The three (3) basal areas (B_A) were established in each sampled plot. All the trees in each B_A classes were normally distributed to locate the mean tree. In this way, three (3) mean trees were assessed for each of the 24 sampled plots. This resulted into a total of 72 mean trees, used to estimate the yield per hectare.

The mean tree representing each basal area (B_A) class was located by first counting all the trees in each sample plot and measuring their girths over bark at breast height. All girths values were then converted to diameter while the diameter data were used to calculate their basal area (B_A) using the relationship.

$$D = g/\pi \quad \text{. . . . . (1)}$$

$$BA = \pi d^2 \quad \text{. . . . . . (2)}$$

Where

g = girth (cm)
d = diameter
BA = basal area (m^2)
π = Mathematical constant (P_1) = 3.142

The mean basal area for the class was computed and the trees whose basal area was the closest to the class were located in each class mean. In addition, dominant trees were located in each of the sample plot. These were the two tallest and two largest trees. This is done by measuring to girth of each tree at breast height in the sample plots.

2.5 Measurements of Site Factors for the Development of Site Index Equation

The measurement of site factors for the development of the site index by investigations which usually consists of multiple regression analyses using stand height (or site index) as the dependent variable and a number of soil properties and other environmental characteristics as the independent variables.

A common approach is to set up the form equation

$$\text{Log } H = b_0 + b_1 \times X_1 \left({}^1/_A\right) + b_2 \times X_2 + b_3 \times X_3 + b_4 \times X_4 \text{ - - } + bn\text{-}1 \times X_N \quad \text{- - -(3)}$$

Where

H = height
A = Age

X_1,X_2,X_3 . . . . .X_N represent soil or other environmental factors (e.g. aspect, slope, elevation, soil characteristics and climatic or topographic factors) [11].

bo . . . . bn-1 are the constants to be solved by least squares.

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

$$\text{Log } SI = b_0 \times b_1 \times X_1 \left({}^1/_A\right) + b_2 \times X_2 + b_3 \times X_3 + b_4 \times X_4 + \text{- - - } + bn\text{-}1\ X_N \quad \text{- - (4)}$$

Where SI = Site Index, i.e. Height at standard age, the other variables are as above, except that $b_0 + b_1 (^1/_A)$ is a constant because age is now constant [11].

2.6 Soil Analysis

The collected soil samples from the various depths of 0-5 cm, 15 cm - 30 cm, 30 cm - 60 cm and 60 cm – 90 cm respectively were sieved (2 mm) in the laboratory and samples were analyzed for: Particle Size Distribution by Bouyoucos-hydrometer method as described by Jaiswal [12]; Soil pH (H_2O) by a pH water Jenway 3015 meter using a soil water ratio of 1:2 after standardizing the pH meter using a buffer solution [12]; Exchangeable Bases were analysed by EDTA titrimetry method using EBT and mureoxide, indicator, while Na^{2+} and K^+ were determined by flame photometer [13]; Available Phosphorus (AVP), using Bray Number one method [13]; Exchangeable Acidity (H^+ and Al^{3+}) by titration using phenolphthalein as indicator [12]; Organic Matter (OM) using the Walkley and Black method [12]; Nitrogen (N) by digestion using conc. H_2SO_4 with Kheldahl method [14]; and Exchangeable Micronutrient (Zn, Fe and Cu) were determined by atomic absorption of spectrophotometer [14].

3. RESULTS

3.1 Development of Site Index Equation of an Age Sequence of *Gmelina arborea* Plantations

The models used in the study to estimate the site index equation were, linear, semi-log, exponential and double log [15]. Ordinary least square (OLS) was used as techniques for estimation. The coefficients of the soil estimated parameters and their corresponding standard error and F-values and adjusted R^2 were shown.

Error term (U_1) is added to these functions form and regression model forms of all these functions are given as follows:

Linear $Y = b_0 + b_1 X_1 + b_2X_2 + \ldots\ldots\ldots\ldots b_n X_n + U_1$ ……(5)

Semi – log $Y = L_nb_0 + b_1L_nX_1 + b_2L_nX_2 + \ldots\ldots b_nL_nX_n + U_1$ ……...(6)

Exponential $Y = b_0\, ae^{b1X1} + b_2x_2 + \ldots\ldots\ldots\ldots b_nX_n + U_1$ ……….(7)

Double–Log $LnY = L_nb_0 + b_1L_nX_1 + b_2L_nX_2 \ldots\ldots\ldots b_nL_nX_n + U_1$ ……….(8)

Koutsoyians [16], suggest that dummy variables can be used in structural comparison. In this study all the variables were included into the model as a whole. The variables used in the site index analysis of the *Gmelina arborea* plantation function model are the following:

Y = Height of the dominant trees (M)
X_1 = Diameter of dominant trees at Breast height (cm)
X_2 = Soil pH (H_20)
X_3 = Soil organic matter (OM) (%)
X_4 = Nitrogen (%)
X_5 = Available Phosphorus (Mg/Kg)
X_6 = Magnesium (Mg^+) C.M.O/(+)/Kg
X_7 = Calcium (Ca) C.M.O/(+)/Kg
X_8 = Sodium (Na) C.M.O/(+)/Kg
X_9 = Hydrogen ions (H^+) C.M.O/(+)/Kg
X_{10} = Aluminum ions (Al^{3+})
X_{11} = Potassium (K) Mg/Kg
X_{12} = Copper (Cu) Mg/Kg
X_{13} = Iron (Fe) Mg/kg
X_{14} = Zing (Zn) Mg/kg
X_{15} = Percentage of Sandy Soil (%)
X_{16} = Percentage of Clay Soil (%)
X_{17} = Percentage of Silt Soil (%)

Table 1 shows the values of parameter estimates for developing a multiple regression model for an age sequence *Gmelina arborea* in Jalingo forest plantations. This also shows that the number of statistically significant (***) parameters varies among functional forms used in the study. However, the F – test results of linear, semi-log, exponential and double-log models, that is 0.612, 0.425, 0.797 and 0.574 respectively, showed that overall regression models were statistically significant ($P \leq 0.05$). Adjusted R^2 was high in linear and semi-log models with 0.84 and 0.82; then exponential and double – log models with 0.72 and 0.48 respectively of adjusted R^2

Table 2 above shows the parameters estimate for developing a regression model for the particle size distribution to an age sequence *Gmelina arborea* in Jalingo forest plantations.

4. DISCUSSION

The pH content of the soil was analyzed based on the soil depth of 0-15 cm, 15-30 cm, 30-60 and 60-90 cm respectively. The results ranged from 6.53-7.17, 6.36-7.03, 6.51-7.04 and 6.48-7.17 respectively. These ranges indicate that, the

Table 1. Estimated parameters for site index of *Gmelina arborea* plantation

Variables	Linear	Semi-log	Exponential	Double-log
Intercep	229.734775***	81.372911	3.488575***	3.196530
	(261.167858)	(744.202943)	(1.19969108)	(3.36003730)
DBH (X_1)	-0.63208	9.562911**	-0.007699	-0.138918
	(1.745697)	(64.8464416)	(0.00744857)	(0.28143327)
PH (X_2)	-25.626961**	43.353711**	-0.058537**	0.421354**
	(34.559283)	(334.0974869)	(0.14745805)	(1.44998160)
Organic matter (X_3)	9.765587***	-5.568067**	0.010644**	0.052156**
	(28.083793)	(27.199485)	(0.11982834)	(0.11804564)
Nitrogen (X_4)	85.741950**	0.760341**	1.203802**	0.142659
	(231.7053141)	(45.284492)	(0.98864358)	(0.19653449)
Available phosphorus	2.649718**	20.754859**	0.024125**	0.138377
(X_5)	(8.6033152)	(79.3894922)	(0.03670875)	(0.34455004)
Magnesium (X_6)	25.224289	33.326682	0.106510**	0.116509**
	(17.07530640)	(48.766009)	(0.07285716)	(0.21164426)
Calcium (X_7)	-5.201239	40.155662	-0.018138	0.205740
	(11.29329260)	(59.156155)	(0.04818638)	(0.25673745)
Sodium (X_8)	-3.581629**	53.896824	-0.012463	0.199670
	(4.87572496)	(145.43010765)	(0.02080381)	(0.63116602)
Hydrogen (X_9)	18.361774	-17.12494**	-0.100558	-0.164333
	(19.48194746)	(52.32896244)	(0.08312385)	(0.22710746)
Aluminum (X_{10})	20.869269	67.391371	0.043928	0.227263
	(24.02750508)	(41.39788178)	(0.10252091)	(0.17966662)
Potassium (X_{11})	13.659804**	17.01137	-0.126881**	0.007395
	(160.016384)	(66.94069348)	(0.68276022)	(029052231)
Copper (X_{12})	-1.697641	-38.221129	-0.007092**	-0.148016
	(1.37049348)	(35.10317935)	(0.00584764)	(0.15234764)
Iron (X_{13})	-2.221342**	-74.495814***	-0.007646	-0.272509
	(1.20101671)	(61.36085538)	(0.00512452)	(0.26630584)
Zinc (X_{14})	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 the parenthesis indicates standard errors; ** Significant at 5 percent ($P \leq 0.05$); *** Significant at 1 percent ($P \leq 0.01$)*

Table 2. Estimated parameters (particle size analysis of the production functions)

Intercep	-4040.547704	-135.924098	127.128503	3.747683
	(17205.983879)	(676.71311136)	(73.74235359)	(2.89702664)
Sandy (X_{15})	41.229455	49.912183	0.302968	-0.009717
	(172.12278266)	(116.09112799)	(0.73677782)	(0.49698917)
Clay (X_{16})	39.654730***	-13.495569***	0.219577**	-0.247928***
	(171.90917625)	(55.90701049)	(0.73677782)	(0.23933938)
Silt (X_{17})	40.145367***	0.709870**	0.299603***	-0.035825***
	(172.03135111)	(28.66836257)	(0.73730144)	(0.12273001)
F – value	0.521	0.446	1.009	0.7802
Adjusted R^2	0.9014	0.6133	0.7802	0.7607

*The values given n parenthesis indicates standard errors; ** Significant at 5 percent ($P \leq 0.05$); *** Significant at 1 percent ($P \leq 0.01$)*

soils in the Gmelina plantation are generally slightly acidic to neutral and mildly alkaline (7.17). The result also revealed that acidity increases with increase in the soil depth. This agrees with Han et al. [17] who reported that top soil is more acidic than subsoil. The results were also in line with the findings of Dregne [18] who reported that the soils of arid and semi-arid regions are slightly acidic to alkaline. Soil pH was also compared in different age plantation. Highest mean value of 7.33 was obtained in 1981 plantation at depth range of 15 cm – 30 cm, while the lowest was obtained at the mean value of 6.36 in 1989 plantation with soil depth of 15 cm - 30 cm.

Semi-log regression model seems to yield better of the equations ($Y = 81.37 + 91.5x_1 + 43.35x_2$ - - - - $b_8x_8+ U_1$). This shows that, the least squares combination of values of the parameters estimates b_0, b_1, b_2 yield less prediction error than possible combination of values; and x_1, x_2, x_3 - - - - U_1, has higher levels of influence on the height of the tree in the *Gmelina arborea* plantations under study when semi-log regression model is used. Therefore, the parameter estimates of diameter at breast height (dbh), soil pH, nitrogen (N), organic matter (Om), available phosphorus (avp), sodium (Na) and potassium (K) were statistically significant to the growth and development of *Gmelina arborea* height (H), while the coefficient of organic matter, sodium (Na) and potassium (K) of the soils carried a negative sign (–).

The results of the study indicated that not all variables contributed fully to the growth and development of the trees height (H) of the *Gmelina arborea* plantations. This is mainly due to poor plantation management and other factors such as outbreak of fire and diseases into the plantation, low organic matter content of 0.52% to 0.97%, low potassium (K) of 0.23 to 0.32 cmol (+) kg^{-1}, and acidity of the soil pH in the plantations of mean values of 6.85, 6.69 etc., human and animals disturbances of pasturing livestock which feed on falling leaves and affects the range of organic matter content and other nutrient contents in the soil.

The above regression models of the particle size distribution in Table 2 indicated that, the number of statistically significant ($P \leq 0.05$ or $P \leq 0.01$) of the parameters vary among the functional forms namely: linear, semi-log, exponential and double-log. Clay and silt were statistically significant to the development and growth of Gmelina plantations with the values of 0.0587 and 0.0405; with F-values of 0.521 and 0.446 respectively. Clay and silt have an adjusted R^2 0.9014 ad 0.613. Linear Regression model seems to yield better in terms of sign and magnitude of the coefficient, which has influence in organic matter retention, hence better nutrient supplies to the plantations. Sandy soil is statistically not significant (0.1310). The percentages of sandy, clay and silt soils obtained from an ages sequence *Gmelina arborea* plantation were generally obtained as: 63.13%, 18.56% and 18.32% respectively; with sandy soil having the highest percentage of 63.13%. This agrees with studies of Bray and Weil [19], who reported that the best agricultural soil is one that has mixture particle such as sandy, loam and silt with percentages of 65, 15 and 20 respectively. Since sandy soil has the highest percentage of 65, it does not support nutrients retention for forest utilization and the plantation can be prone to erosional hazard.

5. CONCLUSION

Elements such as magnesium (Mg), calcium (Ca), Aluminium (Al), copper (Cu) etc. are insignificant in the plantation growth and development. Humans, livestock, constant encroachment have adversely affected the organic matter turnover, because soil enzymes and microbial biomass are responsive to soil disturbance or restoration. Therefore, the conversion of the natural forest ecosystem to monoculture should be discouraged if flora and fauna diversity is to be conserved. Securities should also be deploy to the plantation to constantly check the activities of human and livestock encroachment as well as fire prevention.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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