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SOIL QUALITY AND HEIGHT DIAMETER MODEL ASSESSMENT IN THE MANAGEMENT OF GMELINA ARBOREA PLANTATION IN NASARAWA STATE UNIVERSITY, NIGERIA

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ABSTRACT

Gmelina arborea is a very important timber species as it provides wood for furniture, serves as carbon sink and creates micro-climate with decrease soil temperatures enabling smaller niches to be formed within the forest ecosystem. Also, the nutrients composition of forest soil determines its stand structure and composition, growth rate and dominance, including other silvicultural practices. The study assessed soil quality and height-diameter (H-D) models in the management of *Gmelina arborea* plantation in Nasarawa State University. Thirty (30) temporary sample plots of 0.01 ha size were randomly selected from the sampling frame with 30% sampling intensity. Thereafter, the total height and the Dbh of each tree within the selected plots was measured for height-diameter model assessment. Also, ten (10) soil samples were randomly collected from the thirty (30) selected plots for H-D modeling in order to assess the soil properties of the plantation. Soil samples obtained were analyzed in the Faculty of Agriculture Laboratory to obtain data and further subjected to statistical analysis. The results of height-diameter models revealed that model one (1) with Akaike Information Criterion (62.19), Bayesian Information Criterion (66.39) and Residual Standard Error (0.64) had the lowest model selection indices when compared with other four models applied. Therefore, model one (1) was selected as the best and grand model for *Gmelina aborea* plantation in the study area. Also, the result of soil quality showed a significant difference between the soil properties in the study area. The Least Significant Difference result also showed that Plot twelve (12) had the highest mean soil properties of pH (6.86), Nitrogen (0.35%), Phosphorus (6.61ppp), potassium (0.38Cmol/dm^3), Magnesium (1.28 Cmol/kg) and Cation Exchange Capacity (6.14) when compared to the other nine (9) soil samples. The research showed that plot area beyond 0.1ha varied in soil properties and qualities, consequently resulted to different stand structure in the study area.

Keywords: Models, Soil Quality, Plantation, *Gmelina arborea*

INTRODUCTION

Gmelina arborea is a deciduous tree speciesfound in tropical Asia, Australia, New Guinea and Nigeria (FCEC, 2016).It is economically vital to Nasarawa State communities as it provides wood for furniture; bed frames, arm chairs, cupboards, tables, cabinets, carving images, paper making, toys, canoes, match manufacture and packing cases (Wang, 2004). The tree species is also socially paramount as it creates a favorable micro-climate with decrease soil temperatures enabling smaller niches to be formed within the forest ecosystem (Jose *et al*., 2008), the tree serves as canopies cover to plant and animals to protect them from extreme irradiation and heat effects, which invariably increases the rate of water loss by these plants (Lopez-Pintor *et al.,* 2000). The leaves, root and fruits of the tree species are used as a feedstuff in India and Nigeria. Its fruits and leaves have been reported to contain several chemical constituents having medicinal value (González, 2004). Therefore, there is a need to adequately assess the soil quality of the plantation for proper management of its tree growth attributes.

The nutrients composition of forest soil determines its stand structure and composition, growth rate and dominance, including other silvicultural practices (Poudel and Sah, 2003).The capacity to access productive forest soil relies on the knowledge of physical and chemical properties of the soil. There is a growing interest for assessing the properties of soil and management practice consequences on the soil quality as it relate to the functioning of ecosystem sustainability as well as productivity of the plants. Soil quality concept include the processes and soil property assessment as it relates to effective functioning of healthy component of the ecosystem (Schoenholtz *et al*., 2000). The total amount of nutrients present in soil varies from soil to soil and depends on the nature and chemical composition of the parent materials and other processes of formation. Out of the total nutrients present in the soil, it is the soil nutrients available that is important and can be determine chemically for tree up-take by suitable testing methods (Reddy *et al*., 2012).

Forest health depends on the quality of soil properties of a given forest soil. Soil quality is a function of the amount of soil nutrients available for tree up-take in forest soil (Tiwari *et al.*, 2006), especially the essential forest soil nutrients; N, P, and K. It is an indicator of a limiting factor for trees growing on lowland tropics of relatively fertile soil (Wright *et al*., 2010). Nitrogen is abundantly available in the atmosphere and constantly recycle among tree plants through air, soil and water necessary for tree growth, vigor and structural development, phosphorus is vital for resistance of diseases, root development and the formation of seeds while potassium is responsible for normal cell division in young meristematic tissues of the tree plants. Soil pH is a paramount property which unveils the acidity and alkalinity of soil solution by which it can be used to predict the availability of plant nutrients, toxins and activity of many essential microorganisms (KC *et al*., 2013).

Height-Diameter models are expressed mathematically and relate to tree's measurable variables such as the tree heights and diameters. The average content of trees species with various sizes can be estimated by models (Avery and Burkhart, 2002). The ability to predict growth and yield of a forest stand in various site conditions is the criteria for the development of ecologically management plan and strategies which is based on the growth and yield model of a plantation. The most common procedure is to use an established height and diameter model to predict tree height form of the stand measurement (Adeyemi and Adesoye, 2010). It involves measuring the diameters and heights of the trees to predict the yield of the stand and to identify the best statistical model that fit the management of the plantation stand

Information such as average total heights and diameter at breast height are not available for the stand management. Where such problem thrives, quantitative data would not be available to support the decision making on tree growth rate management. It also has gross deficit of information on its soil quality which can be obtained by investigating soil properties of the plantation. Soil quality include the processes and soil properties assessment as it relates to effective functioning of forest health ecosystem. Effective management entails optimum allocation of growth resources such as mineral elements for proper functioning of the trees. It also aids the estimation of variables which are difficult to be measured such as tree height, volume among others. Therefore, the study aimed to assess soil quality and height-diameter models in Nasarawa State University Forestry *Gmelina abrorea* Plantation with specific interest indeveloping height-diameter models, investigating soil quality and assessing the correlation among the soil propertiesfor tree growthmanagement.

Hypothesis

H_0: There is no significant difference between the soil pH of the plots

H_A: There is a significant difference between the soil pH of the plots

MATERIALS AND METHODS

Study Area

The experiment was carried out at *Gmelina arborea* plantation site of the Department of Forestry and Wildlife Management, Faculty of Agriculture, Lafia, Nasarawa state University, Keffi, Nigeria with longitude 8^o 32N and latitude of 8^o 33E. Lafia is located in Guniea savannah zone of North central Nigeria at the altitude of about 177m above the sea level. The mean monthly maximum temperature range is between 35.06^{0}C to 36.40^{0}C and 20.16^{0}C to 20.50^{0}C while relative humidity and rainfall are 74.67% and 168.90mm respectively. Tropical ferruginous soils make up the major soil units found in Lafia Local Government Area.The parent material for the soils are from basement complex and sedimentary formations in thearea. Laterite crust occurs extensively on the basement complex rocks while hydromorphic soils are common along river Benue trough and flood plains of major rivers (Lyam, 2000).

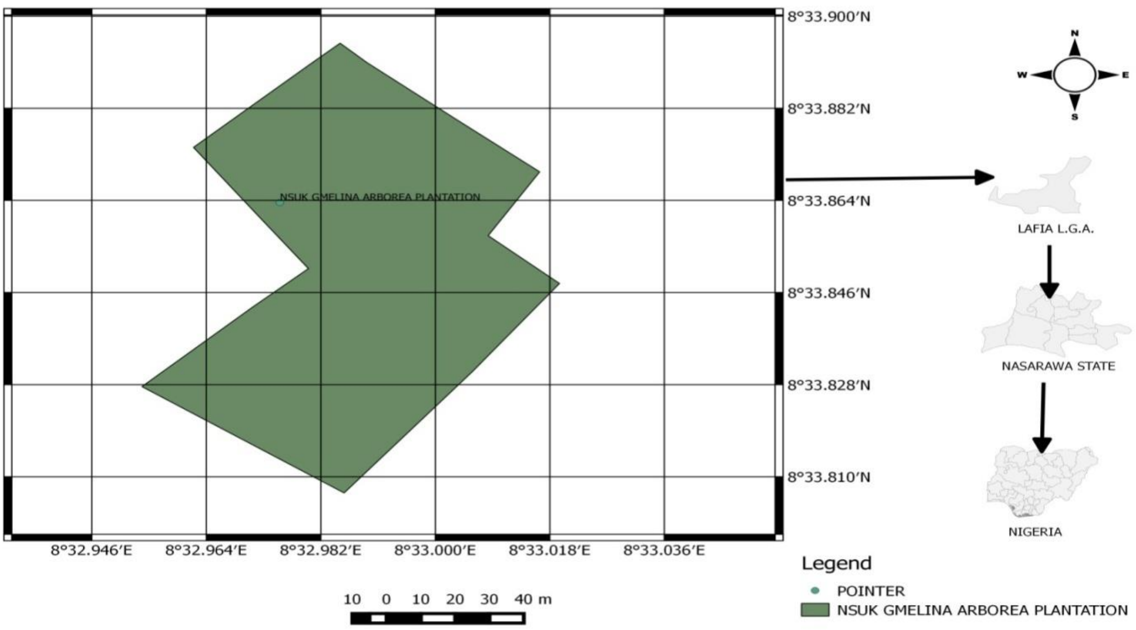

Figure 1: Nasarawa State University Forestry *Gmelina arborea* plantation

Sampling technique

Thirty (30) temporary sample plots of 0.01 ha size was selected from the sampling frame of the plantation with 30% sampling intensity. The plotswere randomly selected and individual trees within each plot were measured. The diameter at breast height (at 1.3 m above ground level) was measured using a diameter tape. Total heights was measured using Haga altimeter and Global Positioning System (GPS) was used to take the coordinates of the study area.

Data collection

Data collected include total height and Diameter at the breast height (DBH).

Soil sample collection

The soil sample was taken at 0-30cm depth because tree roots absorb most of its nutrients at greater depth. Ten (10) soil sample plots were randomly selected from the thirty (30) sample plots selected for height diameter model assessment and each was replicated three (3) times. The samples were labeled in a polythene bag and taken to the soil laboratory of Faculty of Agriculture, Nasarawa State University for further laboratory analysis.

Soil physicochemical properties

The soil pH was determined in distilled waterby using pH meter as described by (Abua 2012) which Beckman zero pH meter is been suspended in distilled water of ratio 1.2.m. Total Nitrogen (TN) was determined by the Micro Kjeidahi digestion method (Abua 2012). Available phosphorus (AVP) was obtained by weighing 1g of the soil sample then adding phosphorus exacting solution using the conventional Bray-1 (Bray and Kurtz, 1945). Potassium in the extract was determined through flame photometry. Organic matter in the soil was determined by the Walkley, (1934) potassium dichromate wet oxidation method.Exchangeable Acidity was determined by using the titration method, which the soil sample is leached with 1Nkcl five times with 25ml each time, the exchangeable Al^{3+} and H^{+} in the leach was determined using titration with 0.05 NaOH in the presence of phenopthualium indicator of which five drops was added and the end point as determined.Cation exchange capacity was determined by calculating the percentage of base saturation.

Table 1: Height Diameter Models for the Plantation

MODEL CODE	MODEL FORM
1	$H = 1.3 + \frac{(DBH^3)}{(a + b * DBH)^5} + \varepsilon$
2	$H = 1.3 + \frac{(DBH)^3}{(a * +b * DBH^4)^3} + \varepsilon$
3	$H = 1.3 + \frac{(DBH^4 + DBH^3)}{(a * DBH^5 + b)^4} + \epsilon$
4	$H = 1.3 + \frac{DBH^6}{(a * DBH + b * DBH^3)^3} + \varepsilon$
5	$H = 1.3 + \frac{(DBH^4 + DBH^3)}{(a + b * DBH^3)^2} + \varepsilon$

Where h=total height, DBH=diameter at breast height, d= diameter at the base, a=parameters, b=parameters

Statistical evaluation

AIC function:

AIC= 2k-2ln($\hat{L}$)

Where

AIC= Akaike information criterion, K =Number of estimated parameters in the model, ($\hat{L}$) =Maximum value of the likelihood function for the model

BIC Function:

BIC= -2.ln p(x/k)≈ BIC = -2.lnL+k{ln(n)}

Where

x= Theobserved data, n= The number data points in x, the number of the observed or equivalently the sample size, k= The number of free parameters to be estimated i.e the number of regression including intercept, p(x/k) =The probability of the observed data given by the parameter, L=The maximized value of the likelihood functions for the estimated model

Residual Standard Error

RSE=$\sqrt{\frac{1}{n-2}RSS} = \sqrt{\frac{1}{n-2}}\sum_{i=1(yi-\hat{y}i)} 2$

Correlation Analysis

Cross tabulated Correlations of Tree Characteristics in *Gmelina arborea* plantation was computed as follow:

Correlation (r) $= Exy - \frac{(Ex)(Ey)/n}{\sqrt{(Ex^2 - \frac{(Ex)^2}{n})\,(Ey^2 - (Ey)^2/n}}$

RESULT AND DISCUSSION

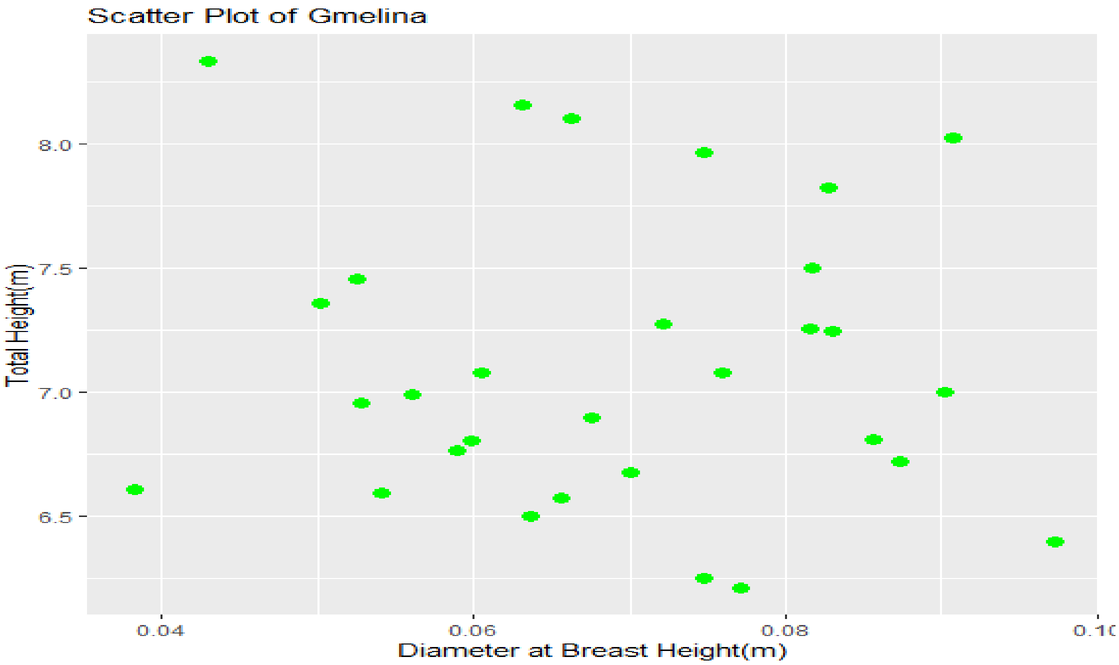

Figure. 2: Scatter Plot of *Gmelina arbora* trees in NSUK Forestry Plantation

The result of scatter plot showed the distribution of total height and diameter at breast height of *Gmelina arborea* trees in Nasarawa State University Plantation. The data points shows the distribution of trees in the plantation.
The result of height diameter model selection indices showed that model one (1) had the lowest AIC (62.19), BIC (66.39) and RSE (0.64). Followed by Model four (4) with AIC (75.01), BIC (79.21) and RSE (0.79), model five (5) with AIC (85.12), BIC (89.32) and RSE (0.94), model two (2) with AIC (104.90), BIC (109.10) and RSE (0.64), and model three (3) with AIC (115.21), BIC (119.10) and RSE (1.55).

Table 2: Height Diameter Models Performance Indices of *Gmelina arborea*

Models	Coefficients	AIC	BIC	RSE	Pr(>|t|)
1	a =0.052491 b= 1.277986	62.19	66.40	0.64	<2e-16 *** <2e-16 ***
2	a =3.950e+02 b =2.767e-02	104.90	109.10	1.30	2.6e-12 *** < 2e-16 ***
3	a= 6.911e+03 b = 7.388e-02	115.21	119.42	1.55	7.43e-10 *** < 2e-16 ***
4	a =0.017314 b =4.265694	75.01	79.21	0.79	<2e-16 *** <2e-16 ***

Aikake Information Criterion (AIC), Bayesian Information Criterion (BIC), ***(p<0.05), Residual Standard Error, probability level (Pr(>|t|)) and a, b (model parameters)

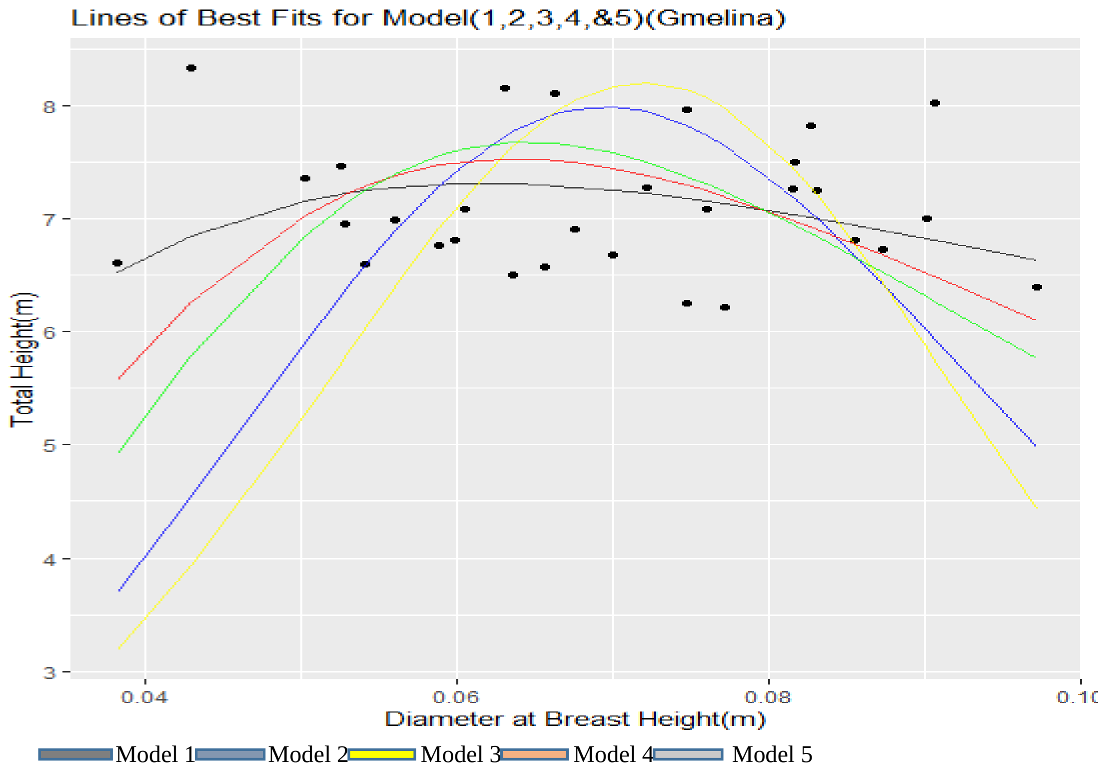

Figure. 3: Lines of best fits of *Gmelina arbora* trees in NSUK Forestry Plantation

The result of line of best fit showed the residuals with deterministic trend of the models. It also showed curves of the five models applied in order of performance; model one (1), model four (4), model five (5), model two (2) and model three (3).
The result of descriptive statistics showed the average value of the selected essential soil properties required for proper growth of *Gmelina arborea* in the plantation site. It revealed that the average value of pH in the plantation site was 6.71 and its standard deviation was 0.09, the mean nitrogen was 0.20% and its standard deviation was 0.07, phosphorus had the mean of 6.01ppm and standard deviation of 0.61, potassium had the mean of 0.30Cmol/kg and standard deviation of 0.11, magnesium had the mean of 1.09Cmol/kg and standard deviation of 0.11, Exchangeable acidity had the mean of 0.70Cmol/kg and standard deviation of 0.13, Cation exchangeable capacity had the mean of 5.41Cmol/kg and standard deviation of 0.36 and Organic matter had the mean of 3.04% and standard deviation of 0.06.

Table 3: Descriptive statistics of the soil properties of NSUK *Gmelina arborea* plantation

Soil properties	Minimum	Maximum	Mean ±Std. Dev.
Ph	6.51	6.87	6.71±.09
N	.13	.35	.20±.07
P	5.07	6.62	6.00±.60
K	.23	.38	.30±.05
Mg	.95	1.31	1.09±.11
E.A	.40	.84	.70±.13
C.E.C	5.01	6.18	5.41±.36
O.M	2.95	3.20	3.04±.06

potential of Hydrogen (pH), Nitrogen (N%), Phosphorus (P(ppp)), Potasium (K(Cmol/kg)), Magnesium (Mg(Cmol/kg)), Exchangeable Acidity (E.A(Cmol/kg)), Cation Exchange Capacity (C.E.C) and Oganic Matter (O.M%)

The result of least significance difference (LSD) showed significant differences between the mean values of the pH, Nitrogen, phosphorus, potassium, magnesium, exchangeable acidity, cation exchange capacity and organic matter.

Table4: LSD Statistics of the Essential Soil Nutrients at the Plantation

Plot	pH	N	P	K	Mg	E.A	C.E.C	O.M
1	6.82b	0.28b	6.57a	0.36b	1.28a	0.49c	6.01b	3.06b
4	6.74c	0.21c	6.48b	0.32c	1.16b	0.67b	5.47c	3.09 b
9	6.73c	0.21c	6.07d	0.31c	1.07cd	0.67b	5.31de	2.99c
12	6.86a	0.35a	6.61a	0.38a	1.27a	0.47c	6.14a	2.99c
19	6.73c	0.21c	6.47b	0.32c	1.08cd	0.67b	5.33d	3.06b
23	6.68e	0.14d	6.25c	0.28d	1.01ef	0.83a	5.29e	3.08b
32	6.71d	0.21 c	6.23c	0.29d	1.03de	0.67b	5.23f	2.96c
34	3.14a	0.14d	5.08f	0.24f	0.98ef	0.83a	5.06g	3.14a
37	6.65f	0.14d	5.17e	0.26e	1.08c	0.83a	5.21f	3.08b
46	6.64f	0.14d	5.14e	0.24f	0.96f	0.83a	5.02h	2.98c

potential of Hydrogen (pH), Nitrogen (N%), Phosphorus (P(ppp)), Potasium (K(Cmol/kg)), Magnesium (Mg(Cmol/kg)), Exchangeable Acidity (E.A(Cmol/kg)), Cation Exchange Capacity (C.E.C) and Oganic Matter (O.M%)

The result of Analysis of Variance showed that soil pH, Nitrogen, Phosphorus, Potassium, Magnesium, Exchangeable acidity, Cation exchangeable capacity and Organic matter all had P-values<0.05.

Table 5: ANOVA table of selected essential soil nutrients

F-Test	pH	N	P	K	Mg	E.A	C.E.C	O.M
F value	460	192.8	1158	99.61	37.83	44.29	972.8	14.91
Pr(>F)	<2e-16 ***	<2e-16 ***	<2e-16 ***	1.25e-14 ***	1.26e-10 ***	2.9e-11 ***	<2e-16 ***	4.75e-07 ***

potential of Hydrogen (pH), Nitrogen (N%), Phosphorus (P(ppp)), Potasium (K(Cmol/kg)), Magnesium (Mg(Cmol/kg)), Exchangeable Acidity (E.A(Cmol/kg)), Cation Exchange Capacity (C.E.C) and Oganic Matter (O.M%) and ***(p<0.05)

The result of cross tabulated correlation values between the selected essential soil property in the study area at two tail 0.01 and 0.05 significant level showed that soil pH, N, P, K, Mg, O.M and C.E.C were positively correlated with other properties. The result also revealed that the strongest relationship was observed between Potassium and Nitrogen.

Table 6: Correlations of the Selected Soil Properties in *Gmelina arborea* Plantation

	pH	N	P	K	Mg	E.A	C.E.C	O.M
pH	1							
N	.887**	1						
P	.845**	.746**	1					
K	.939**	.940**	.872**	1				
Mg	.834**	.854**	.656**	.882**	1			
E.A	-.861**	-.937**	-.758**	-.910**	-.820**	1		
C.EC	.875**	.919**	.714**	.923**	.938**	-.878**	1	
O.M	-.407*	-.318	-.178	-.197	-.044	.311	-.116	1

potential of Hydrogen (pH), Nitrogen (N%), Phosphorus (P(ppp)), Potasium (K(Cmol/kg)), Magnesium (Mg(Cmol/kg)), Exchangeable Acidity (E.A(Cmol/kg)), Cation Exchange Capacity (C.E.C) and Oganic Matter (O.M%),**. Correlation is significant at the 0.01 level (2-tailed) and *. Correlation is significant at the 0.05 level (2-tailed)

DISCUSSION

Height diameter (H-D) modeling is a vital tool for estimating and managing tree heights growth, particularly, in a given plantation. It would be an abysmal to engage in measuring total heights of all trees in a given plantation in the course of carrying out a project due to the difficulties in visibility and fatigue posed by canopy cover (Clement, 2023). Therefore, five (5) H-D models were developed and applied to predict the heights of trees in the plantation. Based on the model selection indices considered, the result showed that model one (1) had the lowest selection indices of AIC (62.19), BIC(66.39), RSE(0.64) with intercept (0.05) and slope (1.277986) when compared to other four models. It implied that, to every 1cm increased in diameter at breast height (Dbh), the tree height changed by 1.28m. The model is quite apt as it had only Dbh in its integral function which is easy to measure and exponential increment was positive, indicating an increasing growing trend of trees in the plantation. It is based on this premise that model one (1) was selected to be suitable for predicting tree heights in the plantation.

The quality of a given forest plantation site determines the rate of productivity potential of the site. The result of soil quality assessment revealed that soil pH, Nitrogen, Phosphorus, Potassium, Magnesium, Exchangeable acidity, Cation exchange capacity and Organic matter were all significantly different, that is, $p<0.05$. It implied that there was nutrients disparity among the soil sample plots which is the only controllable source of variation considered in the experiment. Although, the essential soil nutrients of interest were available in all the sample plots investigated but at different proportions.

The LSD result showed that Plot twelve (12) had the highest mean soil properties of pH (6.86), N (0.35%), P (6.61ppm), K(0.38Cmol/kg), Mg (1.28Cmol/kg), CEC (6.139) when compared to the other samples in the study area. It was ascertained from the result that most of the essential nutrients considered were present in plot one (1) but not clear of its availability for the *Gmelina arborea* tree growth. The result from the soil property showed that soil properties such as pH, N, P, K, Mg, E.A C.E.C and O.M of the plantation need to be improved in order to have a near even soil nutrients distribution within the plantation. Nitrogen is necessary for tree growth, vigor, structural development, and phosphorus is vital for resistance of diseases, root development and the formation of seeds while potassium is responsible for normal cell division in young meristematic tissues of tree plants. Soil pH is a paramount property which unveils the acidity and alkalinity of soil solution by which it can be used to predict the availability of plant nutrients and activity of many essential microorganisms. Among the three major macronutrients, N affects the organic structure, physiological characteristics and biomass synthesis and distribution of plants, and has the greatest effect on dry matter production (Zhu *et al.,* 2014, Lin *et al.,* 2016, Schmierer *et al.,* 2021). P is found in essential biomolecules, including nucleic acids, ATP and phospholipids, which is closely linked to energy metabolism (Poirier and Bucher, 2002). K^+ is used as a major solute to maintain turgor and drive irreversible and reversible changes in cell volume, and it also plays an important role in numerous metabolic processes. Indeed, the circulation of K^+ in the phloem serves as a form of decentralized energy storage that can be used to overcome local energy limitations (Dreyer *et al.,* 2017).

The result of` cross tabulated correlation of the selected essential soil property in the study area showed that soil pH, N, P, K, Mg, O.M and C.E.C were positively correlated with other properties. The result also revealed that the strongest relationship was observed between Potassium and Nitrogen. Elements such as nitrogen (N), phosphorus (P) and potassium (K) are the most essential nutrients for plant growth and development (Ye *et al.,* 2019; Wang *et al.,* 2021b). Plant growth demands large amounts of these macronutrients (Bernstein et al., 2019).

CONCLUSION

The result of H-D model showed that model one was appropriate for predicting tree heights in the plantation. The result of the soil quality assessment showed that Plot twelve had the highest mean soil properties of pH, N, P, K, Mg and CEC when compared to other soil sample collected in the study area. It is ascertained from the result that most of the essential nutrients considered were present in plot twelve for *Gmelina arborea* tree growth. The research showed that plot area beyond 0.1ha varied in soil properties and qualities, consequently resulted to different stand structure in the study area.

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