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SITE INDEX EQUATION FOR *GMELINA ARBOREA* PULPWOOD PLANTATIONS IN OLUWA FOREST RESERVE, NIGERIA

Jonathan C. Onyekwelu*

Department of Silviculture and Forest Management, Ludwig Maximmilians Universität, München, Germany

&

Joseph A. Fuwape

Department of Forestry and Wood Technology, Federal University of Technology, P.M.B. 704, Akure, Nigeria

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ONYEKWELU, J.C. & FUWAPE, J.A. 1998. Site index equation for *Gmelina arborea* pulpwood plantations in Oluwa Forest Reserve, Nigeria. A site index equation for estimating site quality of *Gmelina arborea* plantations in Oluwa Forest Reserve, Nigeria, was developed using a base age of ten years. The plantations age ranged from seven to twelve years. The data were collected from 42 temporary sample plots of 20 × 20 m. The site index (*SI*) equation developed in terms of the dominant height (*Hd*) and age (*A*) was

$$SI = \exp\,[\ln(Hd) + 3.28\,(0.1 - A^{-1})]$$

A site index curve was also developed. Based on this curve, the plantation was divided into five site quality classes. A 12-y-old stand was found to have a site index range of 20.8 to 43.2 m among these five classes, showing that *G. arborea* is growing well in Oluwa Forest Reserve.

Key words: Site index equation - site quality - productivity - *Gmelina arborea* - Oluwa Forest Reserve

ONYEKWELU, J.C. & FUWAPE, J.A. 1998. Persamaan indeks tapak di ladang *Gmelina arborea* kayu pulpa di Hutan Simpan Oluwa, Nigeria. Persamaan indeks tapak untuk menganggarkan kualiti tapak ladang *Gmelina arborea* di Hutan Simpan Oluwa, Nigeria dimajukan menggunakan umur asas sepuluh tahun. Umur ladang berjulat di antara tujuh hingga dua belas tahun. Data diambil dari 42 plot contoh sementara dengan

**Author for correspondence and current address: Department of Forestry & Wood Technology, Federal University of Technolgy, P.M.B. 704, Akure, Nigeria.*

keluasan 20 x 20 m. Persamaan indeks tapak (SI) ditubuhkan bagi ketinggian dominan (*Hd*) dan umur (*A*) ialah:

$$SI = \exp [1n (Hd) + 3.28 (0.1 - A^{-1})]$$

Keluk indeks tapak juga didirikan. Berdasarkan keluk ini, ladang ini dibahagikan kepada lima kelas kualiti tapak. Di antara kelima-lima kelas ini, dirian berumur 12 tahun didapati mempunyai julat indeks tapak di antara 20.8 hingga 43.2 m. Ini menunjukkan bahawa *G.arborea* tumbuh dengan baik di Hutan Simpan Oluwa.

Introduction

Site index is defined as the average total height of specified trees in a forest stand at an arbitrary or base age (Powers 1973). The base age is commonly selected to lie close to the rotation age, though this makes little difference in practice. The base age commonly used in Nigeria for estimating the site index of *Gmelina arborea* is ten years (Greaves 1973, FORMECU 1991a, Onyekwelu 1995). In an even-aged stand, site index is estimated by determining the average total height and age of dominant or co-dominant trees (Avery & Burkhart 1983). Site index is little affected by varying density and species composition; it is relatively stable under varying thinning intensities and is strongly correlated with volume. The true objective of site index is not to predict height at an index age, but to determine the height development pattern that the stand is expected to follow throughout the rest of its rotation (Clutter *et al*. 1983). It can be evaluated mathematically by the use of models or graphically, the mathematical approach being preferable because the graphical method involves an element of subjectivity as well as the difficulty in performing statistical tests on the goodness of fit of the curve.

Site index is a measure of site quality and by far the most commonly used technique for estimating site quality or productivity of a stand (Clutter *et al.* 1983). It is the oldest, commonest and most satisfactory concept for evaluating site quality of a forest stand (Husch *et al.* 1983, Smith & Watts 1987). Site quality is defined as the timber production potentials of a site for a particular species or forest type (Clutter *et al.* 1983). In other words, site quality evaluates the innate productive capacity of an area of forest land for one or more species. Site quality assessment is very important in forest management, because a site could support one species excellently while on the other hand supporting another species poorly. It is therefore important to assess the ability of a particular site to support tree growth or how well a particular species is utilising a site. Site quality can be classified through a site index curve. It is an essential tool required by foresters to manage their forest estates effectively (Sutter 1981).

Gmelina arborea is a very promising multipurpose plantation species. It was introduced into Nigeria in 1921 (Mckay 1943) and has since gained wide acceptance because of its fast growth, excellent yearly fruiting and ease of establishment. It is a major plantation species in Nigeria and has been found to adapt to a wide

range of sites, ranging from deep rich soils of the south to savanna soils of the north. The prominent management objective of *Gmelina* in Nigeria is for pulp and paper production. By 1990, a total of 89 377 ha of *G. arborea* plantations had been planted in various parts of the country (FORMECU 1991b). This accounted for 41.4% of the total plantations in the country.

Planting of *G. arborea* in Oluwa Forest Reserve started in 1980 with the aim of producing pulp raw material for the proposed Iwopin paper mill. It is managed on a rotation age of eight years. The reserve has been noted to be productive, with an average volume of 376.65 m^3 ha^{-1} eight years after planting (Onyekwelu 1995). Research has been conducted on various aspects of Oluwa Forest Reserve (Odunlami 1988, Ogunlade 1993, Onyekwelu 1995), but no definite equation for assessing the relative productive capacity for the *Gmelina* plantations in the reserve has been formulated. It was the aim of this study to develop an adequate site index equation that would be used in assessing the site quality of *G. arborea* in Oluwa Forest Reserve, Nigeria. Site index curves for *G. arborea* in the reserve would also be generated. This would aid in stratifying the plantations into site quality classes as well as determining the development pattern that the *Gmelina* stands in Oluwa Forest Reserve are expected to follow throughout the remainder of their rotation.

Methodology

Study area

This study was carried out in Oluwa Forest Reserve, Ondo state, Nigeria, located at 6° 55'- 7°20' N, 3° 45'- 4°32' E. The annual rainfall ranges from 1500 to 2500 mm. The daily average relative humidity is about 84%. Average annual temperature is about 27 °C. The soils are the ferruginous tropical type underlain by undifferentiated basement complex rocks. The soil is deep and well-drained.

Six age groups were selected for this study from the plantations established between 1980 and 1992. These were 1982 to 1987 plantations. There was no planting in 1988. Plantations established in 1980 and 1981 were not accessible while plantations established from 1989 to 1992 were considered too young for this study since only a 5-year intercept can be used to obtain their site indices.

Data collection

The selected plantations (1982 to 1987), which covered a total area of 6194 ha of land, were stratified into six age classes. Each age class was divided into 20 × 20 m (0.04 ha) temporary sample plots out of which seven sample plots were randomly selected, giving a total of 42 temporary sample plots. Measurements taken in each sample plot included: diameter at breast height (dbh) of all trees; dbh of two mean trees whose basal areas were closest to the mean basal areas of the plot as well as their total height, their diameters at the base, middle and top; and the total height of four dominant trees which were the trees with the largest dbh per

plot (these represented the 100 largest trees per hectare), the mean of these dominant trees serving as the dominant height per plot. The age of the stand was obtained from records.

Development of the site index equation

The base age of ten years was used in developing the site index equation for Oluwa Forest Reserve. Also, dominant height and stand age were used. Among the various techniques for developing site index equations, the guide curve method (Clutter *et al.* 1983) was found adequate for this study. This is because the data were obtained from temporary sample plots, thus permitting only the use of this method. Linear regression models were preferred to non-linear regression models because of the asymptotic properties of non-linear models and the difficulty of obtaining solutions to their parameters (Newnham 1988). Therefore, a linear model was used for this study.

The equation fitted to the dominant height-age curve/regression to obtain estimates of the regression parameters was

$$\ln(Hd) = \beta_0 + \beta_1 A^{-1} \qquad (1)$$

where
- ln = natural logarithm
- Hd = dominant height
- β_0 = intercept value uniquely associated with each particular site index
- β_i = slope with the same value for all site indices
- A = age.

Equation (1) was originally suggested by Schumachar (1939) and is a special case of the simple linear regression model

$$Y = b_0 + b_1 X \qquad (2)$$

where
- Y = dependent variable
- X = independent variable
- b_0 & b_1 are regression coefficients.

Akindele (1991) and Clutter *et al.* (1983) noted that by definition, Hd [in equation (1)] equals site index when A [in equation (1)] equals the base age (10 years in this study). We then have

$$\ln(SI) = b_0 + b_1 (0.1) \qquad (3)$$

where
- SI = site index.

Making b_0 the subject of equation (3) we have

$$b_0 = \ln(SI) - b_1 (0.1) \quad (4)$$

By substituting equation (4) into equation (1), we have

$$\ln(Hd) = \ln(SI) - 0.1b_1 + b_1 A^{-1} \quad (5)$$

By making *SI* the subject of equation (5), we have site index equation as follows:

$$SI = \exp [\ln (Hd) - b_1 (A^{-1} - 0.1)] \quad (6)$$

This equation was used to generate site index values for the various stands which were used to construct site index curves for *G. arborea* in the study area. Regression parameters were generated using equation (1), while site index values were generated from equation (6). This was done using the Statistical Package for Social Scientists (SPSS) on an IBM Compatible machine in the Computer Centre of the Federal University of Technology, Akure, Nigeria.

The error of prediction was determined using the model suggested by Gregoire (1987), i.e.

$$Y = \frac{\sqrt{\frac{\Sigma(x - \bar{x})^2}{n}}}{\mu} \times 100 \quad (7)$$

The data that would be used are the site index values that would be generated using the site index equation developed in this study.

Results and discussion

Table 1 shows the stand growth data obtained from *G. arborea* plantations in Oluwa Forest Reserve.

The height-age equation computed in this study is

$$\ln(Hd) = 3.65 - 3.28 A^{-1} \quad (8)$$

Since *A* is equal to the index age (10 years in this study), the dominant height therefore equals the site index. Equation (8) can therefore be written as

$$\ln(SI) = 3.65 - 3.28 (0.1) \quad (9)$$

By making 3.65 the subject of equation (9), we have

$$3.65 = \ln(SI) + 3.28 (0.1) \quad (10)$$

Table 1. Stand growth data for *Gmelina arborea* plantations in Oluwa Forest Reserve, Nigeria

Age (y)	No. of plots	Mean dbh (cm)*	Dominant height (m)*	Mean volume per hectare (m^3)*	Maximum volume (m^3)	Minimum volume (m^3)	Correlation of volume & dominant height**
7	7	16.55 ± 0.33	24.46 ± 0.65	519.90 ± 58.98	809.06	337.85	0.3573
8	7	16.37 ± 0.81	24.96 ± 0.81	376.65 ± 50.77	666.33	281.59	0.9219
9	7	18.10 ± 0.92	27.80 ± 1.49	519.39 ± 58.26	757.26	290.52	0.5313
10	7	17.98 ± 0.40	33.04 ± 1.10	620.15 ± 67.85	771.27	260.38	0.3385
11	7	22.42 ± 1.21	29.72 ± 0.84	713.62 ± 42.44	889.14	537.82	- 0.2301
12	7	25.19 ± 0.95	24.79 ± 0.93	936.42 ± 87.62	1260.24	575.18	0.8530

* Average values ± standard error.

**Value is the correlation of mean height per hectare and mean volume per hectare for the seven sample plots in each age class.

When equation (10) is substituted into equation (8), we have

$$\ln(Hd) = \ln(SI) + 3.28\ (0.1) - 3.28A^{-1} \qquad (11)$$

Therefore, we have the equation for estimating site index for the study area as follows:

$$(SI) = \exp\ [\ln(Hd) + 3.28\ (0.1 - A^{-1}) \qquad (12)$$

This equation was used to compute site index values. Figure 1 shows the site index curves generated in this study.

As can be observed from Figure 1, the best site quality class is site quality class A and the poorest is site quality class E while the average site quality class is class C. A 12-y-old *Gmelina* stand will attain an average dominant height of 20.8 m in site class E, 33.0 m in site class C and 43.2 m in site class A (giving a site index range of 20.8 to 43.2 m). This shows that *G. arborea* is performing relatively well in Oluwa Forest Reserve. Another indication that *Gmelina* stands in the study area are performing well is evidenced by the fact that height development correlated positively with volume production for all the age classes covered in this study except for that of 11 y (Table 1). Figure 1 also shows the height development pattern that *Gmelina* stands in Oluwa Forest Reserve are expected to follow throughout rotation. For example, it is expected that subsequent average height development in a 10-y-old stand with dominant height of about 27.0 m will follow the height development pattern exhibited by site class C throughout its rotation (Figure 1). Similarly, subsequent average height development for a 12-y-old stand, with a dominant height of about 42.5 m, is expected to follow the development pattern exhibited by site class A. A similar site index curve obtained by FORMECU (1991a) for *G. arborea* plantations in Omo Forest Reserve, Nigeria, showed that a 12-y-old *Gmelina* stand attained an average dominant height of 28.0 m on the poorest site and 35.0 m on the best site. In addition, the site index curve produced by Sutter (1981) for old *Gmelina* stands at Omo and Oluwa showed that the site indices range from 22 to 30 m. Also, the site index curve prepared by Greaves (1973) for *Gmelina* in derived savanna of the former Bendel state, Nigeria, reveals that the site indices range from 10 to 27 m, thus indicating that *G. arborea* stands in the study area are performing very well and that they compare favourably with *Gmelina* stands in other regions of Nigeria. The reason for this good performance of *G. arborea* in the study area can be attributed to the good soils. The soils of the study area are ferruginous tropical soils which are among the most fertile soils in southwestern Nigeria (Akindele 1991). They are deep and well-drained and support *Gmelina* growth as well as those in the natural habitat of *Gmelina* in Burma and elsewhere in southeast Asia.

The error of prediction for equation (12) is 6.64%, thus indicating that the model has a high precision and as a result it is adequate for predicting site index for Oluwa Forest Reserve. The residuals from site index prediction were randomly distributed among the age classes. The only exception was for age 12 y where the equation generally over-estimated site index.

In order to estimate the value of site index for *G. arborea* in Oluwa Forest Reserve using equation (12), the age of the stand as well as the average dominant height is required. For example, for a 9-y-old *Gmelina* stand with average dominant height of 24.96 m, the site index is

$$SI = \exp [1n(24.96) + 3.28 (0.1 - 9\text{-}1)] = 24.07 \text{ m}$$

With equation 12, site indices can be estimated for several plantations and their site quality classes determined. Since site index is an important variable in yield estimation, equation (12) will be a useful tool in yield studies in Oluwa Forest Reserve. Guided by the site index equation and curve generated in this study, Oluwa Forest Reserve can be stratified into five site quality classes which are A, B, C, D and E (Figure 1). Every *G. arborea* stand in this reserve, that is within the age range of the data used, will fall into any of the site quality classes presented in this study.

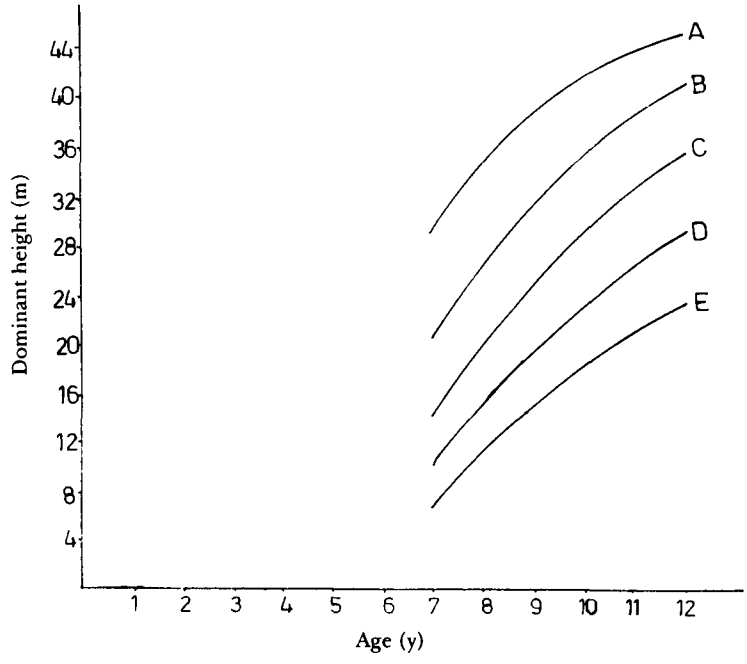

Figure 1. Site index curves for *Gmelina* plantations in Oluwa Forest Reserve, Nigeria

Conclusion

The result of this study shows that *Gmelina arborea* in Oluwa Forest Reserve is effectively utilising the site and that the *Gmelina* stands are productive. Subsequent height development in this reserve is expected to follow the height development pattern exhibited by any of the curves produced in this study. The site index

equation developed in this study is appropriate for determining the site quality of *G. arborea* plantations in Oluwa Forest Reserve. The method used in developing this equation is applicable in other areas. The equation is therefore recommended for use in Oluwa Forest Reserve. It should, however, be applied within the range of the age of the data used in this study.

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