

Yield model and yield table construction in Albizia (Albizia lebbek (L.) under Western Agro Climatic Zone of Tamil Nadu, Southern India

Balasubramanian Arunachalam

Forest College and Research Institute

Hari Prasath Natarajan (✉ prasathforestry@gmail.com)

TNAU: Tamil Nadu Agricultural University

Anjali Satheesan

Forest College and Research Institute

Swathiga Ganesan

Forest College and Research Institute

Radhakrishnan Suthandhirajan

Forest College and Research Institute

Sivaprakash Muthuswamy

Forest College and Research Institute

Manimaran Vellan

Forest College and Research Institute

Navaneetha Krishnan Selvaraj

Forest College and Research Institute

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Abstract

The woody legume, *Albizia lebbeck*, is native to tropical Asia, Africa and Northern Australia. Owing to its multi utility, it is widely planted as block plantation and in boundary across community lands. A field study was conducted by measuring biometric value of trees, viz., height, diameter at every 2 meters height using tree telescope. Besides biometric attributes, age was assessed in order to correlate the age-wise yield. The study was carried out in western agro-climatic zone of Tamil Nadu in different age classes of trees, viz., 1–5 years, 6–10 years, 11–15 years, 16–20 years, 21–25 years, 26–30 years and 31–35 years. The uniqueness of the present study is that, the yield model construction for Albizia was done for standard stem timber (Volume at diameter 20 cm overbark) and standard stem small wood (Volume between diameter limits of 20cm and 5cm both measured overbark). After computing the data and subjected for multiple linear regression analysis, the model was constructed, so as to develop yield table accurately for Albizia without the help of form factor. The study result developed two exclusive yield models namely standard stem timber yield model for Albizia was $Y = (-1.212) + (-0.012 * \text{Age}) + (6.506 * \text{Diameter})$ and standard stem small wood was $Y = (-0.945) + (-0.045 * \text{Age}) + (2.769 * \text{Diameter}) + (0.262 * \text{No. of Branches})$. The prominence of the present study is that yield table computation for Albizia is possible accurately without destructive analysis and the cumbersome process of developing form factor.

Introduction

Albizia (*Albizia lebbeck* L.) is a medium-sized, deciduous, perennial legume tree that is native to tropical Africa, Asia, and Northern Australia. It is also extensively distributed in sub-humid, semi-arid, and tropical areas (Cook et al 2005; Duke 1986; Lowry 1991; Teleni et al 1992). *Albizia* is a species that develops with a mean annual rainfall of 500 to 2,500 millimetres (MSL) with temperatures ranging from 19–35° C and altitudes ranging from 0 to 1800 metres above mean sea level (Cook et al 2005; Lowry 1991). The density of *Albizia lebbeck* wood is 0.55–0.66 g/cm³ or greater (Rao and Juneja 1971; Schroder and Gadow 1999). Farmers produce it in large quantities because of its many practical uses (EcoCrop 2016; Guha and Karia 1981; Orwa et al 2009; Rao and Juneja 1971; Schröder and Gadow 1999). However, due to the lack of yield table species and region, also known as regional volume tables or local volume tables, farmers find it challenging to estimate the yield at the time of sale.

In general, yield models are a series of equations that relate the yield of the tree to age, volume, climatic, edaphic, and topographical parameters in plantations with even or uneven ages (MacKinney and Chaiken 1939; Tewari and Singh 2006). These are techniques that managers and academics can use to forecast future yields and prescribe the best silvicultural practises for managing plantations by utilising appropriate inventory and other resource data (MacKinney and Chaiken 1939; Tewari and Singh 2006; Vanclay 1994). Predictions of when, where, and how much timber may be harvested are necessary for effective harvest planning (Clutter and, Jones EP 1980; Prodan 1997). In order to effectively manage regrowth forests, formulate policies (Wykoff 1982), conduct strategic planning (Vanclay 1994) and manage operations, yield projections are unquestionably important (Seo et al 2015). Regression analysis,

which is widely used in forestry to estimate weight scaling of saw logs (Bower 1962), rates of stem taper (Kozak et al 1969), biomass prediction (Edwards and McNab 1979), yield estimation (MacKinney and Chaiken 1939), and other factors, was used to create the majority of yield models. Traditionally, form factor is constructed to create yield tables, which is a laborious method involving destructive analysis (Tewari and Singh 2006). The volume in 2m billets may be calculated in the current study by using a tree telescope, which measures standing tree diameter at various heights. This benefit is not frequently used when building yield tables for forestry crops.

Some of the yield model prediction in farm grown trees was addressed in *Azadirachta indica* (Raviperumal et al 2017), *Ailanthus excelsa* (Ravi et al 2019), *Ailanthus excelsa* (Balasubramanian 2019), *Tectona grandis* (Suresh krishnan 2017) etc. A full grasp of the model's structure and the interactions between its components is necessary for model evaluation, which should cover all of the model's assumptions and components (Soares et al 1995). The model should be validated by comparing model predictions with actual data if sufficient independent data are available. Errors and the uncertainty in the model structure cannot be found in the absence of such validation data [Suresh krishnan 2017; Voet and Mohren 1994]. With the exception of specific tree species including Teak (*Tectona grandis*), Melia (*Melia dubia*), Ailanthus (*Ailanthus excelsa*), and Gmelina (*Gmelina arborea*), the validation of the established yield models was considered to be of least concern in forestry (Suresh krishnan 2017). Therefore, the goal of this study was to create preliminary growth and yield models, validate them for management, and act as a foundation for further research into the growth and yield of *Albizia lebbbeck* in Tamil Nadu's Western Agroclimatic Zone.

Materials And Method

Study Area

The field study was conducted in Western agro climatic zones of Tamil Nadu including Coimbatore (11.01°N, 76.95°E), Erode (11.34°N, 77.71°E), Tiruppur (11.10°N, 77.34°E), part of Namakkal (11.22°N, 78.16°E), Karur (10.96°N, 78.07°E), Ariyalur (11.14°N, 79.07°E), Perambalur (11.23°N, 78.88°E), Theni (10.00°N, 77.47°E), and Dindigul (10.36°N, 77.96°E) districts of Tamil Nadu during 2020–2021. Data consolidation and computation were carried out at Forest College & Research Institute, Mettupalayam, Tamil Nadu

a) Estimation of volume

The biometric observations in standing trees viz., Height, diameter at breast height, diameter at 2 m intervals with simple random sampling were taken by using Tree telescope (Leica DISTO™ D810) at various age classes including 1–5 years, 6–10 years, 11–15 years, 16–20 years, 21–25 years, 26–30 years and 31–35 years.

At 2 m intervals, the diameter of each tree was measured, and the mid-diameter was determined for each billet. In order to approximate the volume of a single tree, quantities of 2 m billets were eventually heaped

up. For standard little wood, i.e. volume within diameter limits of 20cm and 5cm, both measured overbark, the measurement is taken from ground level to the limit of the piece of tree stem or branch where diameter is 20 cm overbark. Volume of the trees were estimates by using the formula Chaturvedi and Khanna (1982),

$$V=\pi r^2h \quad (1)$$

Where,

r- Radius of tree at different height intervals

h –Commercial Bole Height

b) Construction of yield models

Age and average diameter (of standard stem timber and standard stem small wood) were employed as independent variables for yield modelling by regression analysis, and merchantable volume was used as a dependent variable. Standard stem small wood volume and standard stem timber volume were added to determine the total volume. When measuring with a tree telescope, the form factor was disregarded because the diameter was measured every two metres in height.

The multiple linear regression analysis was done by means of IBM SPSS (Statistical Package of the Social Science). The general linear regression equation used for constructing the yield model was (Kieman et al 2021; Vanclay 1994)

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + \dots + b_n X_n (2)$$

Where, Y – Yield (m³)

a – intercept (Constant)

X₁ – age of the tree in years

X₂ – Average Diameter

b₁, b₂ – Regression coefficients of b₁ and b₂

c) Validation of yield models

The Residual Plot Analysis method was used to validate the produced yield models (Alder and Synnott 1992). The creation of the yield model does not employ the biometric data chosen for the validation. Using the aforementioned process, the actual volume of the chosen biometric data was calculated, and the constructed model was then utilised to calculate the predicted volume. To verify the model, the same

data's anticipated and actual volumes were regressed. To investigate the consistency of the proposed yield model, a chi-square test for goodness of fit was performed.

Results And Discussion

Yield model for *Albizia lebbeck* with particular reference to Western agro-climatic zone (Coimbatore, Erode, Tiruppur and part of Namakkal, Karur, Ariyalur, Perambalur, Theni and Dindigul) of Tamil Nadu were constructed by using multiple linear regressions by equation (Balasubramanian 2019) are given below ($R^2 = 0.7069$)

Yield model for standard stem timber

$$Y = (-1.212) + (-0.012 * \text{Age}) + (6.506 * \text{Diameter})$$

Yield model for standard stem small wood

$$Y = (-0.945) + (-0.045 * \text{Age}) + (2.769 * \text{Diameter}) + (0.262 * \text{No. of branches})$$

The predicted yield table for *Albizia lebbeck* is presented in the Table 2. The predicted yield table developed for *Albizia lebbeck* was developed for 7 age classes *Viz.*, age class of 1-5 years, age class of 6-10 years, age class of 11-15 years, age class of 16-20 years, age class of 21-25 years, age class of 26-30 years and age class of 31-35 years. The diameter classes were framed for preparation of yield table was 0.10 m, 0.20 m, 0.30 m, and 0.40 m and these diameter of the tree was divided into standard stem timber (Fig.1) and standard stem small wood. Among seven age-classes, maximum total height (18.37 m) and diameter (0.52 m) was observed in age class 31-35 years followed by age class of 26-30 years (17.04 m and 0.43m respectively). The study concluded a strong positive correlation with the height and diameter increment in Albizia, similar trend was also observed by O'brien et al (1995) for timber species in Uganda.

The standard stem timber volume of 0.000 m³, 0.024 m³, 0.060 m³, 0.254 m³, 0.456 m³, 1.072 m³ and 1.779 m³ were recorded during age class of 0-5 years, 6-10 years, 11-15 years, 16-20 years, 21-25 years, 26-30 years and 31-35 years respectively. The similar observation were recorded is standard stem small wood volume with maximum volume of 1.509 m³ (31- 35 years) and minimum during 0-5 years (0.034 m³). The total volume of these seven age classes were arrived by summing the standard stem timber volume and standard stem small wood volume. The total volume in Albizia was attained maximum in 31-35 years (Fig.2) with the value of 3.288 m³ and minimum volume of 0.034 m³ at 0-5 years was recorded (Table 1). The study result observed that the volume increased with age and diameter in almost all age classes, similar observation was recorded in *Gmelina* and *Ailanthus* (Suresh Krishnan 2017), *Acer saccharum* (Dey et al 2017), *Pinus densiflora* (Seo et al 2015), *Abies alba* (Marziliano et al 2019) etc. In the yield study on Norway spruce at 40 years of age by Johansson (2014) also indicated that the tree yield increases with increase in diameter and age attained the yield up to 0.17 m³ at 40 years. The study infers that the mean annual increment of merchantable stem volume showed steady increasing trend in the age of the plantation up to 31-35 years. These results were in consonance with the results of Nunifu

(1997) that the growth of timber tree species (*Tectona grandis*) was steadily increasing with age and also achieved peak MAI of plantations at the age of 48 years.

The model prepared was validated (Table 3) according to Alder and Synnott (1992), the result revealed that except for higher age class (31-35 years) the deviation from predicted to actual timber volume is less, ranging from 2 % to 7 % for both standard stem timber and standard stem small wood with P value of Chi square test as 1 and R^2 value ranging from 0.006-0.009. Hence the constructed model is significantly validated with the adopted procedure. The similar study on validation of the farm grown tree species namely *Tectona grandis*, *Melia dubia*, *Gmelina arborea* and *Ailanthus excelsa* were carried in Western agro-climatic zone and Cauvery delta agro-climatic zone of Tamil Nadu. Suresh Krishnan (2017) inferred that the predicted volume was 5 to 9 per cent deviated from the actual volume observed in all the four species. The minimum residual sum of square was observed from the present study and the observed chi-square value confirms the good fit of model to the data in *Albizia lebbeck*.

Other than the species of the trees in a stand, the stand characteristics that most obviously affects growth and yield is stand age (Chaturvedi and Khanna 1982; Johansson 2014; MacKinney and Chaiken 1939). In the present study, the yield model developed in Albizia based on the age and biometrics predicts the merchantable volume for Albizia where, the yield is positively correlated as a function of diameter for standard stem timber and as a function of diameter and number of branches for standard stem small wood. Similar procedures of model formulations were found practically applicable in non-destructive yield model preparation of trees species, such as yield model developed in *Ailanthus excelsa* (Balasubramanian 2019; Ravi et al 2019) , *Tectona grandis* (Suresh Krishnan 2017; Prasad et al. 2017), *Azadirachta indica* by Raviperumal et al. (2017) where in neem the merchantable volume is obtained maximum at the age of 26-30 years than comparing with 31-35 years, hence these yield prediction equations can be manipulated for fixing rotation age of the crop by foreseeing the merchantable volume for harvest.

Conclusion

The yield table has been developed for both standard stem timber and standard stem small wood and the validation has been carried out with minimum residual mean sum of square (R^2) ranging from 0.006 to 0.009. The validation infers only 2 to 7 per cent deviation from the actual volume observed. Hence the yield table developed can be used as local volume table for *Albizia lebbeck* developed for Western agro climatic zone of Tamil Nadu.

Declarations

All authors are ready to afford all financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

The authors give consent for the publication of identifiable details, text, tables, and figures to be published in the above journal.

Authors Contributions

Dr. Balasubramanian Arunachalam, Dr. Hari Prasath Natarajan, Ms. Anjali Satheedan, Dr. Swathiga Ganesan, Dr. Sivaprakash Muthuswamy and Dr. Radhakrishnan Suthandhirajan, contributed to the conceptualization, investigation and writing original draft and Mr. Manimaran Vellan and Navaneetha Krishnan Selvaraj contribute to review, editing and preparation of the final draft.

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Competing Interests

The authors declare that they have no competing interests" in this article.

Availability of data and materials

All data generated or analyzed during this study are included in this manuscript article and some of the datasets generated during and/or analyzed during the current study are not publicly available.

All authors are ready to afford all financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

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Tables

Table 1. Merchantable volume of *Albizia lebbbeck*

Age class (Years)	Total height (m)	Clear boleheight(m)	Average diameter(m)	Standard stem Timber volume(m ³)	Standard stem small wood volume(m ³)	Total volume(m ³)
1-5	4.16±1.9	1.54±0.12	0.10±0.05	0.000±0.23	0.034±0.23	0.034±0.45
6-10	6.25±1.8	2.18±0.14	0.17± 0.04	0.024±0.17	0.079±0.22	0.103±0.40
11-15	6.75±1.9	1.81±0.12	0.22±0.04	0.060±0.20	0.104±0.20	0.164±0.40
16-20	8.97±1.9	2.38±0.12	0.26±0.05	0.254±0.23	0.286±0.23	0.540±0.45
21-25	12.27±1.9	2.41±0.11	0.32±0.05	0.456±0.23	1.021±0.22	1.477±0.45
26-30	17.04±1.8	2.37±0.14	0.43±0.06	1.072±0.23	1.376±0.22	2.448±0.45
31-35	18.37±1.9	2.38±0.12	0.52±0.04	1.779±0.17	1.509±0.23	3.288±0.40

Table 2. Yield table for *Albizia lebbbeck* in Western agro-climatic zone of Tamil Nadu

AGE (years)	Diameter class																							
	0.10 (m)						0.20 (m)						0.30 (m)						0.40 (m)					
	Standard stem timber volume (m³/tree)	Standard stem small wood volume (m³/tree)					Standard stem timber volume (m³/tree)	Standard stem small wood volume (m³/tree)					Standard stem timber volume (m³/tree)	Standard stem small wood volume (m³/tree)					Standard stem timber volume (m³/tree)	Standard stem small wood volume (m³/tree)				
		Number of branches						Number of branches						Number of branches						Number of branches				
1-5	-	1	2	3	4	5	0.149	1	2	3	4	5	0.800	1	2	3	4	5	1.450	1	2	3	4	5
		-0.631	-0.369	-0.107	0.154	0.416		-0.354	-0.092	0.169	0.431	0.693		-0.077	0.184	0.446	0.708	0.970		0.199	0.461	0.723	0.985	1.247
6-10	-	2	3	4	5	6	0.209	2	3	4	5	6	0.860	2	3	4	5	6	1.510	2	3	4	5	6
		-0.594	-	0.332	0.070	0.191		0.453	-0.317	-0.055	0.206	0.468		0.730	-0.040	0.221	0.483	0.745		1.007	0.236	0.498	0.760	1.022
11-15	-	3	4	5	6	7	0.269	3	4	5	6	7	0.920	3	4	5	6	7	1.570	3	4	5	6	7
		-0.557	-	0.295	0.031	0.228		0.490	-0.280	-0.018	0.244	0.506		0.768	-0.003	0.259	0.521	0.783		1.045	0.274	0.536	0.798	1.060
16-20	-	5	6	7	8	9	0.329	5	6	7	8	9	0.980	5	6	7	8	9	1.630	5	6	7	8	9
		-0.258	0.003	0.265	0.527	0.789		0.019	0.281	0.543	0.805	1.067		0.296	0.558	0.820	1.082	1.344		0.573	0.835	1.097	1.359	1.621
21-25	-	7	8	9	10	11	0.389	7	8	9	10	11	1.040	7	8	9	10	11	1.690	7	8	9	10	11
		0.040	0.302	0.564	0.826	1.088		0.318	0.580	0.842	1.104	1.366		0.595	0.857	1.119	1.381	1.643		0.872	1.134	1.396	1.658	1.920
26-30	-	9	10	11	12	13	0.449	9	10	11	12	13	1.100	9	10	11	12	13	1.750	9	10	11	12	13
		0.339	0.601	0.863	1.125	1.387		0.617	0.879	1.141	1.403	1.665		0.894	1.156	1.418	1.680	1.942		1.171	1.433	1.695	1.957	2.219
31-35	-	11	12	13	14	15	0.509	11	12	13	14	15	1.160	11	12	13	14	15	1.810	11	12	13	14	15
		0.638	0.900	1.162	1.424	1.686		0.916	1.178	1.440	1.702	1.964		1.193	1.455	1.717	1.979	2.241		1.470	1.732	1.994	2.256	2.518

Table 3 Validation of yield model by estimating the actual and predicted volume in *Albizia lebbbeck*

Age class (Years)	Standard stem timber volume (m ³)		Residual mean sum of square	Standard stem small wood volume (m ³)		Residual mean sum of square
	Actual volume (m ³)	Predicted volume (m ³)		Actual volume (m ³)	Predicted volume (m ³)	
6-10	0.060	0.077	0.006	0.078	0.095	0.008
11-15	0.059	0.029	0.006	0.103	0.111	0.009
16-20	0.254	0.268	0.007	0.285	0.459	0.008
21-25	0.455	0.540	0.006	1.020	0.873	0.007
26-30	1.071	1.225	0.008	1.375	1.358	0.009
31-35	1.212	1.725	0.007	1.509	2.170	0.008
P value of Chi square test			1	P value of Chi square test		1

Figures

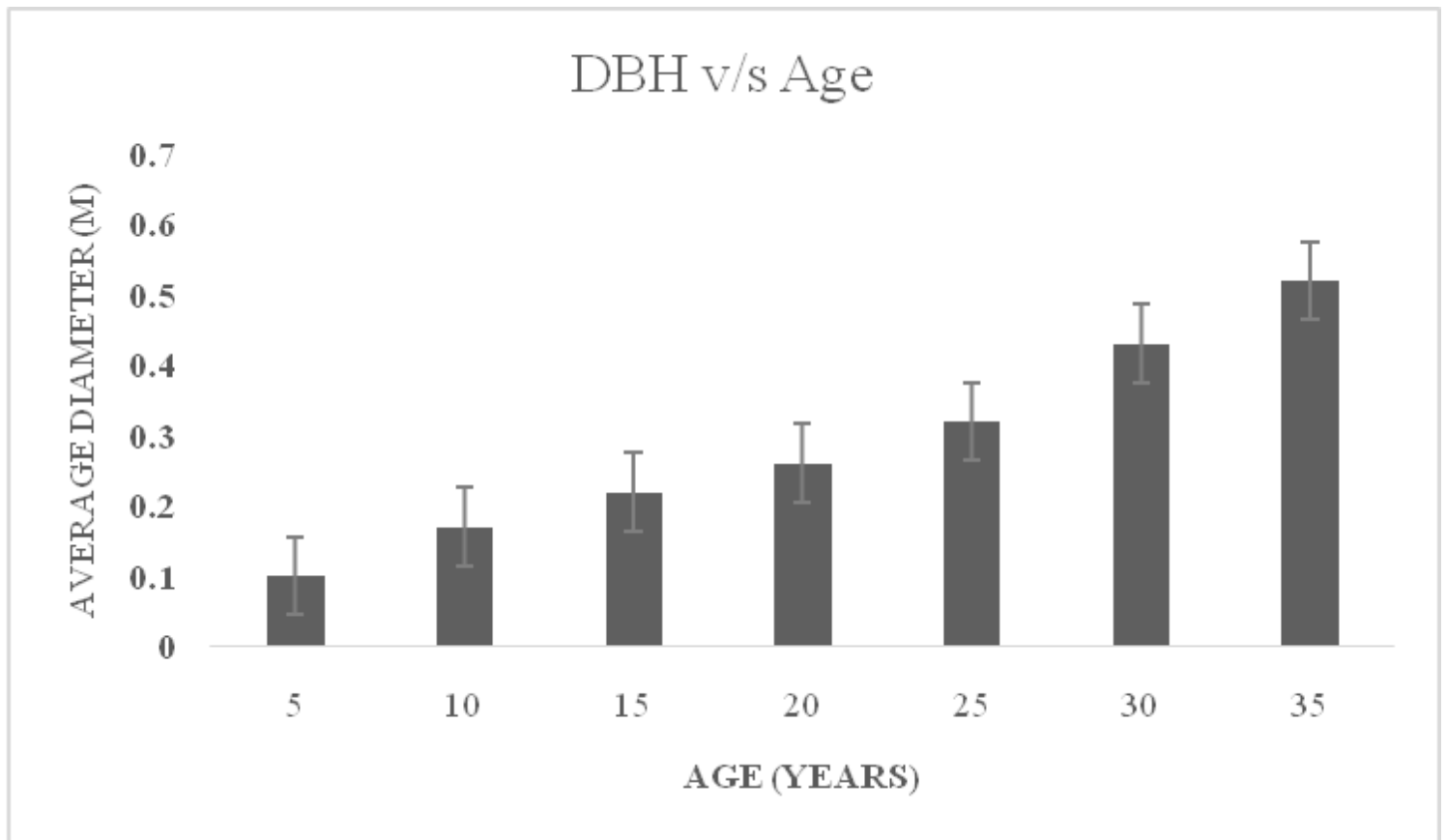


Figure 1

Diameter increment in *Albizia lebbeck* with age

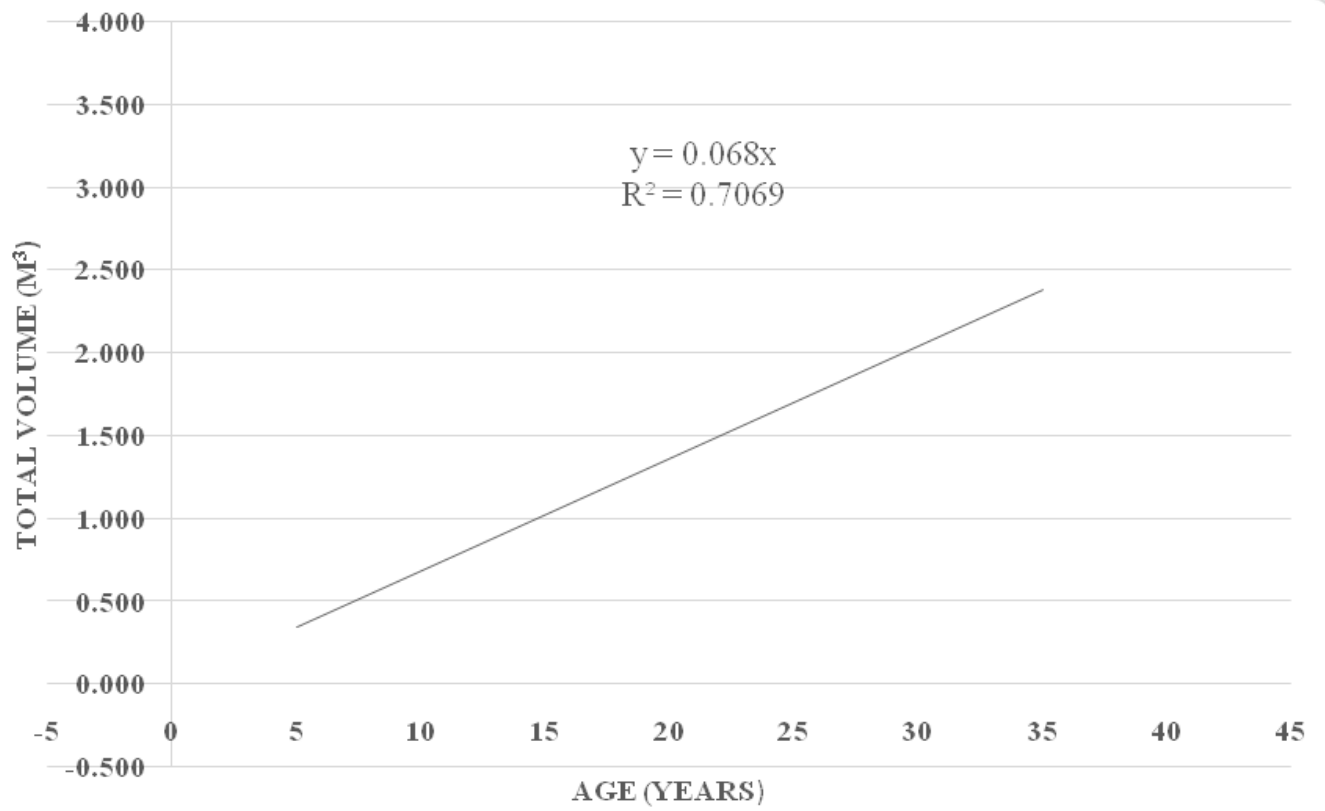


Figure 2

Volume increment in *Albizia lebbeck*

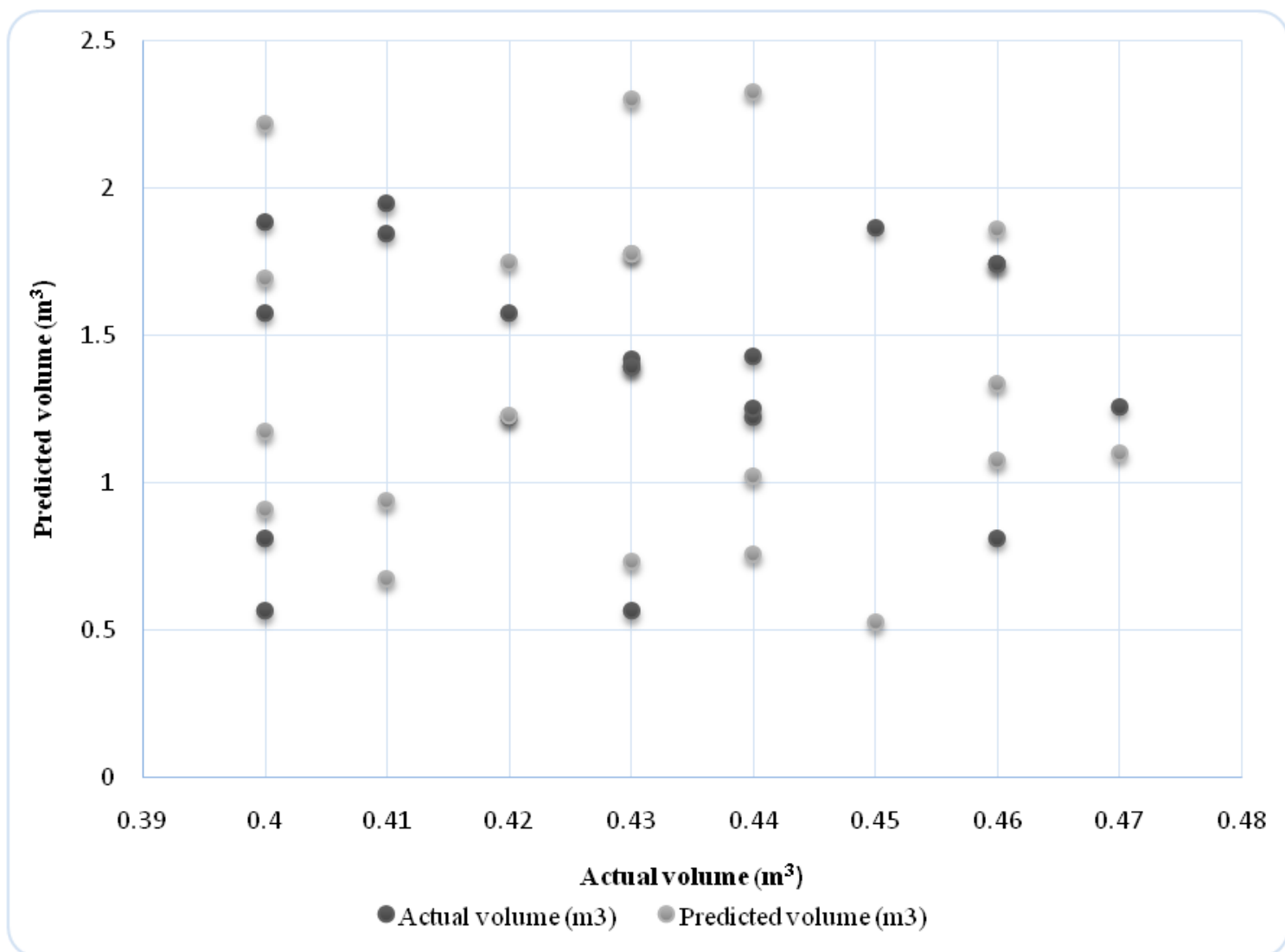


Figure 3

Relationship between Actual volume and Predicted volume in *Albizia lebbeck* (26-30 years)