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Growth and Yield Prediction Models for Ash (*Fraxinus angustifolia* Vahl.) Plantations in Turkey

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Abstract

Ash (*Fraxinus angustifolia* subsp. *oxycarpa* [Bieb. ex Willd.] Franco & Rocha Afonso) is a very fast growing species that has been introduced in the plantations in Turkey for its faster growth and high range of adaptability. Ash forests formed pure stands along the alluvial delta on Sakarya stream of the East Marmara Sea region. In spite of the importance of ash, information on the growth and yield of this species is still not sufficient. In this study, growth and yield characteristics of volume and volume elements in ash forests were investigated in Adapazarı region of Turkey. Data were collected from 27 temporary sample plots from plantations ranging in age from 16 to 36 years. Models selected for ash plantations estimated number of trees, stand mean diameter, stand mean height, stand dominant height, stand basal area and total volume yield. Growth and yield characteristics of ash stands were investigated for different stand age, site index and stand densities. Relationships were determined with multiple regression analysis. Paired t- test, 45 degree line test, percent absolute deviation (AD%) and biological principle of stand development were used for the validation of chosen models. The stand number of trees, stand mean diameter, stand mean height, stand dominant height, stand basal area and stand volume yield models explain 77.4 %, 84.7 %, 92.9 %, 83.5 %, 97.3 % and 95.2 % of the total variation, respectively.

Key words: Basal area, site index, volume and volume elements, multiple regression analysis.

INTRODUCTION

Ash (*Fraxinus angustifolia* subsp. *oxycarpa* [Bieb. ex Willd.] Franco & Rocha Afonso) covering approximately 12,500 hectare forest area is one of the most important plantation species in the high forest of Turkey. Ash spreads about 0.06% of forest areas of Turkey [1]. Ash has very high growth rate and consists of valuable wood. It grows on bottomland moist, deep alkali soils and riparian zones of the Marmara Sea and Middle and West Black Sea Regions. Therefore, it has attracted the attentions of many scientists studying on this species [2-8].

Turkey has been facing an increasing problem of acute wood shortage. To deal with this problem ash plantations have been recently implemented in both degraded forest land and marginal bottomlands. In Turkey, annual volume increment of high forest is approximately 3.4 $m^3 ha^{-1}$ [9]. In Turkey, annual volumes increment of ash forests are for natural stand and plantation 15 $m^3 ha^{-1} yr^{-1}$ and 23 $m^3 ha^{-1}$, respectively [10].

Ash forest of Adapazarı- Süleymaniye is the biggest bottomland ash stand in Turkey. It had a total area of 5,150 ha according to forest management plan in the 1960s. Large scale plantations of ash in Adapazarı in Turkey started in the early 1960s, under a fast growing tree species plantation program that was initiated with the help of the Turkish Forestry Service. These plantations, covering about 1,000 ha area, were to supplement the supply of wood products from the indigenous natural forests. A further increase in ash plantations occurred after a 5 yr afforestation program in 1990 under the Turkish Forestry Department, which realized an increase in the extent of existing plantations and the establishment of new plantations in northern Turkey [9].

Growth models are vitally important for forest management planning. Estimating the growth and yield of individual stands is a prerequisite to develop an adequate forest management plans at any level. Therefore, presenting various growth modeling techniques and their limitations can be very valuable for forest managers.

In spite of the importance of ash, information on the growth and yield of this species is still not sufficient. In this study, growth and yield characteristics of ash forests (plantations) were investigated in Adapazarı region in Turkey. The growth and yield prediction models for ash growth in these forests have been tried to be developed. Mean stand diameter, stand mean height, stand dominant height, stand volume, number of trees per hectare and basal area per hectare were calculated based no the data collected from the field. The developmental trends of the volume and yield in the pure stands of ash were investigated for various site index, stand age and stand densities.

MATERIAL AND METHODS

The study area

This research has been carried out in forest areas located in the East Marmara Sea region of Turkey. The study area is between 40° 48’ 08” - 40° 53’ 10” N. and 30° 34’ 22” -30° 37’ 00” E. The average altitude is 20-25 m above sea level and ground slope is 0-2%. The study area is located about 33 km away from the Marmara Sea. Mean annual temperature is 14.2 °C and total annual rainfall is 798 mm. This region is a transitional zone between the Marmara Sea and the Black Sea climate. The study area is identified as a humid region (De Martonne’s dryness coefficient; I=28.01) which is especially seen in the regions with Black Sea climate conditions in Turkey. It has pure or mixed stands in Marmara Sea and Black Sea regions, on the slopes exposing the sea.

Ash forest occurs naturally in the low humid lands of Adapazarı region, Turkey. Hydromorphic alluvial soils cover large areas around the Süleymaniye plain, which is located along the Adapazarı city boundaries. These kinds of soils cause serious problems with respect to drainage. At the beginning of spring soil, surface is usually covered with water. Such areas, usually called bottomland forests, tend to be *Fraxinus* L., *Alnus* Miller, *Salix* L. and *Populus* L. forests. In our study area, ash was the most widespread species. Ash forests formed pure stands along the alluvial delta on Sakarya stream of the East Marmara Sea region. However, there were also individual tree species such as *Ulmus leavis*, *U. minor*, *Acer campestre* and *Quercus robur* in these ash stands [7].

Data collection and analysis

The undistributed, normal canopy, pure, even-aged and plantation ash stands were selected carefully in 2001. The spacings were established as 3.0 x 2.0 m, 3.8 x 3.8 m or 4.0 x 4.0 m. To develop and test growth prediction equation, the data were collected from 27 temporary plots (0.09ha), chosen from plantations throughout Adapazarı region. The number of plots in each plantation was determined based on the proportion of the plantation area.

Diameter at breast height of all the trees in the plot was measured to the nearest 0.1 cm. Heights of trees were measured to the nearest 0.25 m using Speigel Relaskop to estimate the dominant height and volume in the stands. Diameters were measured on each tree while heights were measured only on a subsample of trees.

To determine the acceptable yield models, firstly, stand dominant height (Ho) model was derived. Then, models were derived for stand mean height (H), mean diameter of stand (D), stand basal area per hectare (G), number of stems per hectare (N) and total volume yield per hectare (V). The variables used in this study are: mean age of stand (yr), average dominant height (m), number of stems per hectare (stem ha-1), mean diameter of stand (cm) mean height of stand (m), stand basal area m^2ha^{-1}, stand density and total volume of stand (m^3 ha^{-1}).

The mean age of sample plots was found by using arithmetic average of minimum 8-10 middle tree stump age with the help of pressler increment borer. Basal area was determined based on the total cross- sectional area of the trees in a sample plot. This value was converted into hectare to estimated basal area in per hectare. Mean diameter was obtained by dividing the sum of individual tree diameter by the number of trees in a sample plot. To determine site index dominant height was determined from stand height curve with help of the average diameter of 100 thickest diameter trees per hectare. To find stem volume per hectare in the sample plots volumes of all the trees that are in a sample plot, were added by using the stem volume table [8]. Site index tables for the normally stocked ash plantations were used to determine the site index of each sample plot [10]. In this study, a base or reference age of 20 years was used. Curtis et al. [11], combines basal area and mean diameter of stand to form a measure of stand densities,

$$SD= \frac{G}{\sqrt{D}} \qquad (1)$$

Where

SD= stand density, G= stand basal area per hectare (m^2 ha^{-1}), D= mean diameter of stand (cm).

Table 1 shows the ranges of volume and volume elements for ash stands.

Table 1. Summary of the statistical results derived from the study

Variable	Mean (min-max) ± SD
Number of trees per hectare (stem ha^{-1})	720.6 (348-1555) ± 296.9
Mean diameter of stand (cm)	23.7 (13.6-35.0) ± 6.7
Mean height of stand (m)	23.3 (12.9-34.7) ± 6.6
Top height of stand (m)	26.9 (14.0-36.7) ± 7.0
Age of stand (yr)	26.5 (16.0-35.0) ± 7.4
Site index (m) * standard age (yr)	22.4 (18.1-27.0) ± 2.4 (20)*
Stand basal area (m^2 ha^{-1})	31.0 (9.1-50.7) ± 9.2
Stand volume per hectare (m^3 ha^{-})	374.3 (72.0-782.3) ± 169.9

The estimated model was evaluated based on the statistical requirements and goodness fit [12-14]. The independent variables of the stand yield prediction models were stand age, site index and stand density while the dependent variable was the natural logarithm (ln) of stand yield per hectare. Stepwise and all probable combinations of independent variables were used to select the most suitable model subject to the fulfillment of the statistical and biological requirements. Different transformations of the variables either in the form of ln, reciprocal or combining three variables in the transformed or in the original forms or combinations along with the original variables were used for regression analyses. Independent variables the form of SI, SI^2, 1/SI, ln(SI), 1/ ln(SI) for site index, A, A^2, 1/A, ln(A), 1/ln(A) and SI/A for stand age and SD, SD^2, 1/SD, ln(SD), 1/ln(SD), SD/A i.e. for stand density were used. In this way, equations for stand dominant height, stand mean height, stand diameter, stand basal area, volume and numbers of trees per hectare were derived.

Model validation

Statistical validation

The data were used to develop equations through multiple linear regression techniques. The best models were chosen according to a set of statistics considering the following issues:

- Coefficient of determination (R^2),
- Statistical significance of the coefficients,
- Minimum residual sum of squares value (RSS) and their distribution (this should be close to normality),
- Simple and biologically meaningful expressions.

SPSS, one of the common statistical software packages, was used in statistical analysis.

Biological principle testing

For biological principle testing, predicted number of trees, stand mean diameter, stand mean height, stand dominant height, stand basal area and total volume yield derived from the chosen models were plotted against stand age, site index for different stand densities.

Independent test

Validation of the chosen models was performed by using data from 27 independent sample plots. The actual values of these units were collectively compared with the corresponding values predicted by the chosen models. The comparisons were made with the help of paired t-test and absolute deviation percent. These were also compared through 45- degree line test. The observed and the predicted values were plotted to see the trend of the slope of expected curves. If the expected curves tend to make an angle of 45 degrees with the axes, this means that there is no significant difference between the actual values and the predicted values. The null hypothesis was that there was no significant difference between experimental data and predicted data.

RESULTS AND DISCUSSION

After finding out the site indexes, density levels, volume and yield parameters of the sample plots, the yield parameters of the stand were calculated. Yield parameters such as the number of trees, volumes and basal areas per hectare and mean diameter, mean height of the stands were calculated with the help of three independent parameters including site index, stand age and stand density.

The equations for stand dominant height (Ho), stand mean height (H), stand mean diameter (D), stand basal area (G), number of trees (N) and stand volume (V), as functions of site index (SI), stand density (SD) and stand age (A) are presented in Table 2.

Table 2. The equations for number of trees (N), stand mean diameter (D), stand mean height (H), stand dominant height (Ho), stand basal area (G) and stand volume (V) as functions of site index (SI), stand density (SD) and stand age (A)

$$\ln N = \beta 0 + \beta 1 \left(\frac{SD}{SI}\right) + \beta 2 \left(\frac{\ln(A)}{SI}\right) + \beta 3 \left(\frac{\ln(A.SI)}{SD}\right) + \beta 4\, A \quad (2)$$

$$D = \beta 0 + \beta 1\, (SI.A) + \beta 2\, (SD.A) + \beta 3 (SI.SD.A) \quad (3)$$

$$\ln H = \beta 0 + \beta 1 \ln(SI) + \beta 2\, SD + \beta 3\, (\ln(SI).\ln(SD).\ln(A)) + \beta 4 \left(\frac{1}{A}\right) \quad (4)$$

$$Ho = \beta 0 + \beta 1\, H \quad (5)$$

$$\ln G = \beta 0 + \beta 1 \left(\frac{1}{SI}\right) + \beta 2 \ln(SD) + \beta 3\, A \quad (6)$$

$$\ln V = \beta 0 + \beta 1 \left(\frac{1}{SI}\right) + \beta 2 \ln(SD) + \beta 3 \left(\frac{1}{A}\right) \quad (7)$$

The results of the model evaluation and parameter estimation are given in Tables 3-8. The models are statistically significant since their P- values (the significance probability) are less than 0.001. In practice, models with P- values less than 0.05 are considered valid models since 95 out of 100 model predictions are statistically significant. As the P- value gets smaller, the model predictions get more accurate [14]. The models have very high R^2 values. For example, the model 2 explains 74% (R^2= 0.774) of the total variation in number of trees in ash stands. The stand number of trees, mean diameter, mean height, dominant height, basal area and volume yield models explain 77.4%, 84.7%, 92.9%, 83.5%, 97.3% and 95.2% of the total variation, respectively.

These models provide useful information for forest management and enable rapid and schematic comparisons to be made of the evolution of these important variables, according to stand site index, stand age and stand densities.

Table 3. Statistical analyses for model 2 to predict number of trees ((a) analysis of variance for the model ; (b) t-tests for the model parameters)

	Degree of freedom	Sum of squares	Mean squares	F	P-value
(a)					
Regression	4	2.5991	0.6498	18.8060	<0.0001
Residual	22	0.7601	0.0346		
Total	26	3.3593	0.1292		

Parameters	Value	Standard error	t-value	P- value
(b)				
β0	-8.1466	5.0743	-1.6055	0.1227
β1	17.3365	4.0121	4.3211	0.0003
β2	-0.0044	0.0050	-0.8858	0.3853
β3	3.1924	1.1028	2.8950	0.0084
β4	-0.1618	0.0446	-3.6305	0.0015

Table 4. Statistical analyses for model 3 to predict stand mean diameter ((a) analysis of variance for the model ; (b) t-tests for the model parameters)

	Degree of freedom	Sum of squares	Mean squares	F	P-value
(a)					
Regression	3	977.2356	325.7452	42.5132	<0.0001
Residual	23	176.2310	7.6622		
Total	26	1153.4667	44.3641		

Parameters	Value	Standard error	t-value	P- value
(b)				
β0	4.3712	2.5628	1.7057	0.1015
β1	0.0533	0.0091	5.8674	0.0000
β2	-0.1389	0.0398	-3.4872	0.0020
β3	0.0028	0.0018	1.5157	0.0432

Table 5. Statistical analyses for model 4 to predict stand mean height ((a) analysis of variance for the model; (b) t-tests for the model parameters)

	Degree of freedom	Sum of squares	Mean squares	F	P-value
(a)					
Regression	4	2.1554	0.5388	71.5864	<0.0001
Residual	22	0.1656	0.0075		
Total	26	2.3210	0.0893		

Parameters	Value	Standard error	t-value	P- value
(b)				
β0	1.6334	0.6554	2.4923	0.0207
β1	-0.1352	0.4474	-0.3021	0.7654
β2	-0.4744	0.1072	-4.4260	0.0002
β3	0.2405	0.0634	3.7919	0.0010
β4	10.7438	8.6582	1.2409	0.2277

Table 6. Statistical analyses for model 5 to predict stand dominant height ((a) analysis of variance for the model; (b) t-tests for the model parameters)

	Degree of freedom	Sum of squares	Mean squares	F	P-value
(a)					
Regression	1	1054.5840	1054.5840	126.6480	<0.0001
Residual	25	208.1723	8.3269		
Total	26	1262.7563	48.4676		

Parameters	Value	Standard error	t-value	P- value
(b)				
β0	4.6512	2.0561	2.2622	0.0326
β1	0.9578	0.0851	11.2538	0.0000

Table 7. Statistical analyses for model 6 to predict stand basal area ((a) analysis of variance for the model ; (b) t-tests for the model parameters)

	Degree of freedom	Sum of squares	Mean squares	F	P-value
(a)					
Regression	3	4.1248	1.3749	272.0061	<0.0001
Residual	23	0.1163	0.0051		
Total	26	4.2410	0.1631		

Parameters	Value	Standard error	t-value	P- value
(b)				
β0	2.2893	0.2304	9.9367	0.1227
β1	16.9129	3.2353	-5.2276	0.0000
β2	0.7955	0.0804	9.8924	0.0000
β3	0.0151	0.0028	5.4014	0.0000

Table 8. Statistical analyses for model 7 to predict stand volume ((a) analysis of variance for the model ; (b) t-tests for the model parameters)

	Degree of freedom	Sum of squares	Mean squares	F	P-value
(a)					
Regression	3	7.7754	2.5918	151.9709	<0.0001
Residual	23	0.3923	0.0171		
Total	26	8.1677	0.3141		

Parameters	Value	Standard error	t-value	P- value
(b)				
β0	6.9703	0.5682	12.2683	0.0000
β1	-30.2446	6.0195	-5.0245	0.0000
β2	0.6189	0.1585	3.9051	0.0007
β3	-21.5240	3.1438	-6.8465	0.0000

Statistical validation and biological principle testing

In statistical analysis of the models developed in this study equations of the selected volume elements (diameter, height, volume, number of trees and basal area) produced the highest coefficient of determination (R^2), highly significant values of F and low standard errors i.e. the selected models satisfied all the statistical criteria (Table 2-8). These results indicate statistical acceptability of the selected models. The yield curves were sigmoid, which reasonably satisfied the biological principles of growth and development. The yield curves shifted upward with increasing site index and the yield monotonically increased with time or age of the stand. All these confirmed the ideal attributes of a biological yield curve.

Independent test

The computed t values for all the estimations were less than the tabular t value ($t_{0.001;26}$=3.707). This implies that there were no significant differences between the observed and the predicted values. Thus, the selected models might be acceptable (Table 9).

Table 9. The computed t values, slope and absolute deviation percent (AD%) for stand volume and volume elements

Variable	t value	Slope°	AD%
N	0.057	44.118	13.384
D	0.001	44.690	8.130
H	0.044	44.766	5.696
Ho	0.001	44.712	7.749
G	0.095	44.962	4.885
V	0.217	44.893	8.699

45 degree line test

The observed values and the predicted values generated slopes of more or less 45 degrees. It can be observed that the models tended to make an angle of 45 degrees with the axes, meaning there is no significant difference between the actual and the predicted values. Absolute deviation percent (AD%) between the observed and the predicted values for all the variables were minimum. There is a difference within the range of 4.885 to 13.384 percent between observed and predicted values of the variables (Table 9).

After the confirmation of the validity of the selected models through validity tests, number of trees, stand mean diameter, stand mean height, stand dominant height, stand basal area and total volume yield were estimated and presented in Table 9. Forest users will readily calculate the values of number of trees, stand mean diameter, stand mean height, stand dominant height, stand basal area and total volume yield as desired rather than measuring them for general uses. The yield prediction models and their uses are recommended for stands age of 15-40 yr within the limitations of the data used in the study.

Our growth models (Table 2), are similar to those used in the recent studies [10], thus they are coherent with previous studies and data. The new criterion for our growth model is, however, based on a stand density study, which the old models lacked. Moreover, our new models are fully detailed in their explanation of how each major silvicultural variable progresses with time, thus providing a more useful management tool from the long term point of view.

CONCLUSION

The development trends of volume and yield parameters of ash stands which can grow on various site index, stand age and stand densities were determined under the conditions of Turkey based on the data obtained from 27 temporary sample plots where selected from East Marmara Sea region (ash forests of Adapazarı-Süleymaniye) where ash stands are major land covers.

The models are adequate in Table 2 allow us to generate to predict number of trees, stand mean diameter, stand mean height, stand dominant height, stand basal area and total volume yield for any stand age, site index and stand densities.

Growth and yield models seem to be best tools for designing a thinning regime and are also helpful in matters concerning forest inventorying and management [15,16]. They are also a necessary tool in the resource planning essential to forest policy design. Our yield models might be used in the following cases: a) site index classification of the inventory units, b) the estimation of periodic increment in inventories for forest management, c) production forecasting for regional scale planning.

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