Relationships between Black Pine Wood Production (m^3 per year) and Some Habitat Factors in the East Mediterranean Region

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The present study aims to identify the relations between the wood production (m^3 per year) of the black pine (*Pinus nigra* Arnold.) and its habitat characteristics in the Eastern Mediterranean Region. A total of 120 samplings with different aspects, site altitudes, and site classes were studied. In each sample area, at least 5 trees were designated, and soil samples were taken by excavating earth pits. Certain characteristics of the soil samples were identified in the laboratory environment. The relations between the dominant height values of the trees in the sample areas and soil, climate, and physiographic factors were analyzed using correlation analysis, multiple regression analysis, and artificial neural network methods. Significant relations between the wood production values of the trees in the sample areas and slope from physiographic habitat characteristics, average annual temperature from climate characteristics, and pH and total carbonate from soil characteristics were found. The wood production of black pine was explained by multiple regression analysis at a level of 22.4% and by artificial neural network method at 72%.

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INTRODUCTION

Forest ecosystems are important ecosystems in which all living organisms living both underground and aboveground interact with their surroundings. While it is of high importance to protect species in forest ecosystems, hundreds of plant species are under the threat of extinction at varying degrees (Akman 2011). Protecting these species is essential for sustaining the lives of all other species (Waring and Schlesinger 1985; Mitchell *et al.* 2023).

In the management of forest ecosystems, the ecological, economic, sustainability, and social functions should all be considered (Toman and Ashton 1996). This consideration plays an important role in planning and performing forestry works.

Forests can degrade due to factors such as excessive logging, forest fires, climate change, and harmful pests and diseases. Turkey has approximately 23 million hectares of forest area, and approximately 57.8% of it is fertile and 42.2% of it is degraded (GDF 2021). The degraded areas are subject to afforestation practices, and tree species that are to be planted there should be carefully selected. Areas with inconsistent precipitation and poor soils (referring to soil that lacks essential nutrients, proper pH balance, organic matter, and other vital properties necessary for healthy plant growth) are thought to be more vulnerable to the danger of erosion. For afforestation activities to be performed in these areas to be successful, the use of species adaptable to existing ecological conditions and with deep root systems is required. It is known that deep roots hold the soil better and decrease the surface flow (Turna *et al.* 2006). Black pine is a resilient tree species with high adaptability. It has a deep root system that helps in soil retention and prevents erosion. Black pine can thrive even in dry and rocky areas and can tolerate low nutrient levels. (Urgenc 1998). Because of these characteristics, black pine, which is an important species in Turkey's forests as in the world forests, is frequently preferred to increase the success in afforestation with continental climatic conditions (Campo *et al.* 2019; Ayan *et al.* 2021; Lucas-Borja *et al.* 2022). In terms of the forest industry, the height and diameter increments of trees are higher in rich sites compared to poor sites. Therefore, the highest wood production (m^3) can be achieved by choosing the site where the species will develop best in afforestation studies.

This study was carried out to determine the relationships between black pine wood production and some habitat factors in the East Mediterranean Region. This study also aimed to determine the method with the best predictive power.

In addition, the study area is Kahramanmaras province of Turkey, where the 7.7 earthquake destroyed the settlements. This study supports the economic and industrial activities in the province because of its contributions to forest products production and city development.

EXPERIMENTAL

Study Area

The study area is in the north of the district Andirin, Kahramanmaras, which is located in the south Anatolia Region, Turkey.

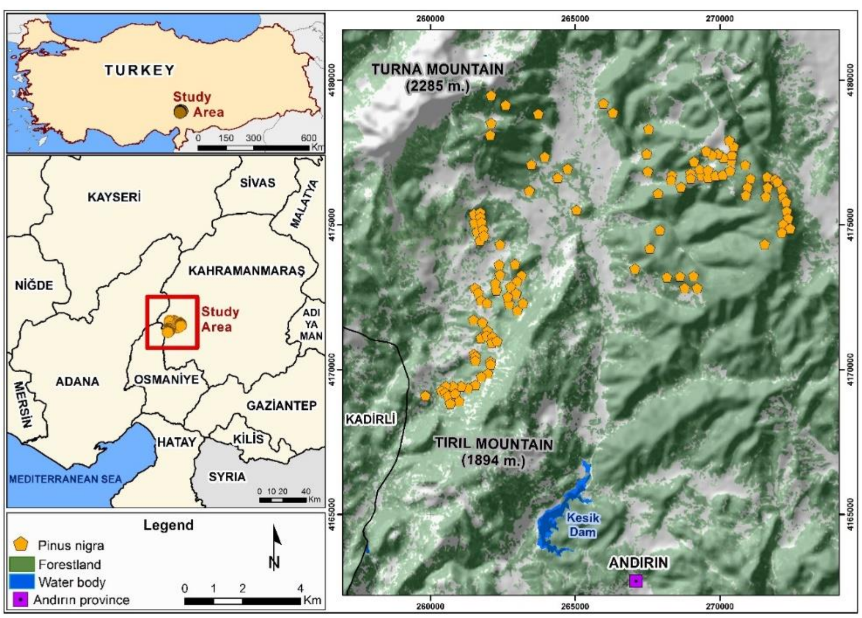

Fig. 1. Study area

The study area is 90 km from Kahramanmaras and 12 km from Andirin. The study area is in the west of the city and is located between 37° 38' 10" and 37° 43' 54" north latitudes and between 36° 16' 41" and 36° 25' 9" east longitudes. The majority of the study area is hilly. The Binboga Mountains (2830 m), a continuation of the Taurus Mountains, are in the north. The southernmost mountain from South-East Taurus Mountains is Mount Ahir (2301 m), which is located north of the Kahramanmaras Plain. Mount Engizek (2814 m), Mount Berit (2917 m), and Mount Nurhak (3090 m) are located north of it. Mount Baskonus (1775 m) and Mount Karlik (2061) from Amanos Mountains are located in the south (Gurbuz 2011) (Fig. 1).

The study area was located in the transitional zone of Mediterranean climate and continental climate. According to the climatic data of the region between 1930 and 2021, the highest temperature was 45.2 °C, which occurs in June, and the lowest temperature was -9.6 °C in February. The average annual temperature is 16.7 °C. The average total annual rainfall of the region is 721.6 mm (TSMS 2022). The location with the highest rainfall in and around Kahramanmaraş is the Andirin district, where the study area was located. This is mainly because the district is situated in a location against air movements, bringing abundant rainfall because of the climatic characteristics and distribution of forest areas over a large surface. The humid air coming from the Mediterranean Sea produces rainfall in the district, depending on high mountains and forests (Karabulut and Cosun 2009).

While the study area was predominantly made of brown forest soil, alluvial and colluvial soil types also exist in the area. The soil type characteristics of the basin are largely formed by vegetation and climatic factors. Brown forest soil is the dominant soil type in the region. The existence of large amount of brown forest soil in the study area is primarily because of the rich vegetation in the region, which is caused by climate (Korkmaz 2000).

Sampling of the Land and Laboratory Analyses

Samplings were performed in 120 sample areas with different altitude, aspect, and slope characteristics. Sample areas were selected as rectangular (20 m x 10 m) and in a size (200 m²) that could cover at least 15 trees (Cepel *et al.* 1977). The site is one of the most important factors affecting the wood production of trees. In favorable sites, trees have a higher height and diameter increase potential compared to poor sites. Therefore, the highest wood production potential can be reached by choosing the site where the species will develop best in afforestation studies. Upper height was selected as the wood production measure, as it reflects yield power better compared to diameter or volume and is less affected by stand density (Firat 1972; Kuzugudenli 2022). The tallest 5 trees in each sample area were designated; and age was measured using an increment borer and tree height was measured using a clinometer. While selecting the sample trees, it is considered that they should not have forks, broken tops, and deformed trunks. The site index (SI) has been determined as a wood production measure. It was obtained by indexing the age and height values to 100 years (Kalıpsiz 1963).

To obtain soil variables, an earth pit was excavated in each sample area, and undegraded soil sample was taken. Texture (sand, dust, or clay) (Bauyoucos 1951), suitable humidity, available water capacity (Kacar 2009), organic substance (Jackson 1958), total carbonate (lime) (Kacar 2009), and pH (Yang *et al.* 2019) were determined from the soil samples.

The location (latitude, longitude), slope, altitude, and aspect of the sample areas were determined. GPS was used for location, a clinometer was used for slope (%), an altimeter was used for altitude, and a compass was used for aspect. Results related to physiographic factors were checked by a 1/25000 scale contour map (Eriksson and Holmgren 1996; Zech and Cepel 1972).

Following the land studies, climatic variables were obtained. A total of 19 climatic data were obtained using current climate maps available in 2.1 format at http://www.worldclim.org (Hijmans *et al.* 2005). As a result of these, 29 different habitat variables were recorded, which would be associated with the SI of black pine.

Statistical Analyses

The data were statistically analyzed *via* SPSS statistical software (version 21.0, SPSS Inc., Chicago, IL, USA) using Pearson correlation analysis, principal component analysis, and regression analysis. First, independent continuous variables were related using Pearson correlation analysis method. Before the modelling process, the process of data filtering among descriptive variables was performed. At this stage, principal component and correlation analyses were performed to identify the variables that might cause multiple-connecting problems in the models (Ozdamar 2002; Thompson 2004).

After all of these steps, the process of modelling the relation between the wood production of black pine and its habitat was initiated, and multiple regression analysis (MRA) and Artificial Neural Networks (ANN) were employed, respectively (Cohen *et al.* 2003; Aertsen *et al.* 2010; Kuzugudenli 2018). The Artificial Neural Networks (ANN) data obtained from experimental studies were modelled using the MATLAB Neural Network Toolbox.

A multiple regression model (MRM) is one of the most used and known logical techniques that mathematically explains the relation between two or more variables. This method gives information about whether there is a relation between variables and, if any, the degree of the relation. However, equations formed using MRA method can only give accurate and reliable forecasts under the assumptions that the errors of models are normally distributed, error variances are homogeneous, and there is no correlation between independent variables (Orhunbilge 2002).

Artificial neural networks (ANN) are mathematical models inspired by the operation of the human brain. The models use computer software to imitate the communication principle among neurons, which are human brain cells. In the ANN model, there are layers in which interrelated neurons exist (Elmas 2003; Chandwani *et al.* 2015) (Fig. 2).

Based on the form of interconnected neurons, the activation function and learning rules create various network structures. These are categorized into three classes, such as radial-based, feedback, and feed-forward neural networks. Among the models, a feed-forward neural ANN structure was employed, and the Levenberg–Marquardt (LM) learning algorithm, which is one of the supervised learning algorithms, was preferred. LM combines the speed of the reduced gradient method and the Newton method. It is the fastest algorithm among the back-propagation algorithms (More 2006). In the study, this learning algorithm is preferred because it is fast and has a low learning error.

In the present study, models with 5, 10, and 20 neurons were formed, and these models were compared when determining the neuron number.

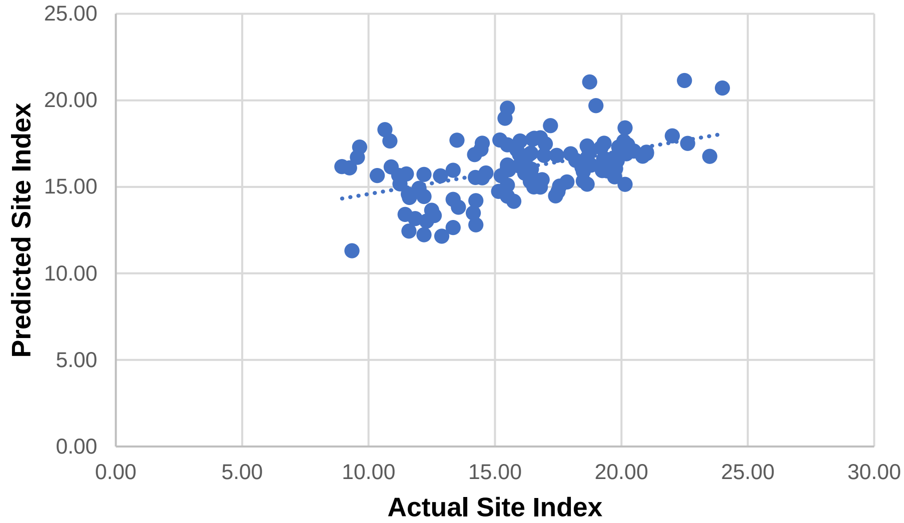

Fig. 2. Relationship of actual and predicted SI for Regression Model

It is stated in the literature that the performance and accuracy of ANN can be improved using certain normalization methods applied to data (Masters 1993). There are many normalization methods, and the Min-Max method is generally preferred. With this method, extremely large data on the models are decreased (Oztemel 2003).

RESULTS

In the study, the site values indexed to 100 years ranged between 8.95 and 24.00 mm in the 120 sample areas. First, bilateral relations were analyzed with the correlation analysis, which indicated that the climatic variables were highly correlated. Because the high correlation might cause multi-connecting problems, the most representative variable was chosen. According to the results of principal component analysis, which was applied to choose the most appropriate climatic variable, two components were obtained, whose variance was larger than 1 and whose variance participation was larger than 10%. It was found that the first component’s variance contribution rate was 65.9%, that of the second component was 15.8%, and the total variance contribution rate of these two variables is 81.8% (Table 1).

Table 1. Principal Component Analysis (PCA) Results

Components	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)
1	12.529	65.942	65.942	12.529	65.942	65.942
2	3.003	15.807	81.749	3.003	15.807	81.749

According to Table 2, it was decided that the climatic variables BIO6 (Mean Diurnal Range, maximum temperature − minimum temperature) and BIO7 (Mean Temperature of Coldest Quarter), which had the highest coefficients among the components, would be used in the study.

Table 2. Principal Component Analysis (PCA) Results

Components	1	2	Components	1	2
BIO1	0.996	0.073	BIO11	0.997	0.036
BIO2	-0.366	0.893	BIO12	0.990	0.004
BIO3	-0.381	0.677	BIO13	0.996	-0.010
BIO4	0.511	0.699	BIO14	0.356	0.242
BIO5	0.962	0.265	BIO15	0.934	-0.112
BIO6	0.998*	-0.009*	BIO16	0.996	-0.018
BIO7	-0.304	0.913	BIO17	0.181	0.198
BIO8	0.997	0.036	BIO18	-0.183	0.459
BIO9	0.993	0.111	BIO19	0.996	-0.018
BIO10	0.992	0.114			
* Components that had the highest coefficient					

As a result of the correlation analysis applied in SPSS, the relation between the site index value of black pine and total carbonate (r = 0.246) and pH (r = 0.189) was statistically significant ($p < 0.05$) and they were positively related. Further, the relation between the site index value of black pine and BIO7 (r = -0.195) and Slope (r= -0.402) were statistically significant and they were negatively related (Table 3).

Table 3. Coefficients of Bilateral Relations between Variables

	Sand	Clay	Silt	AWC	Lime	pH	BIO6	BIO7	Aspect	Slope	Altitude
SI	0.11	-0.10	-0.002	-0.060	0.036	0.246*	0.189*	0.083	-0.195*	-0.402**	-0.087
* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)											

After bilateral relations were identified, multivariate statistical analyses were performed. Slope, total carbonate, pH, and BIO7, which had a significant relation with SI in MRA from multivariate statistical analyses, constituted the productivity model of black pine (Table 4).

Table 4. Prediction Success of Multiple Regression Analysis Model

R	R^2	Adjusted R^2	Std. Error (Estimate)
0.473	0.224	0.197	3.29603

Following the regression analysis, the step of ANN modelling was initiated. To predict the site index, Slope, Total Carbonate, pH, and BIO7 were selected as input variables. A total of 90 of the datasets of 120 sample areas were randomly selected as training datasets and 30 as test datasets. Before starting the training of artificial neural networks, Min-Max normalization was applied to all data.

Upper height forecasts of these three models were obtained using the test dataset. The R^2 value of the model formed with five neurons (5N-ANN) was 0.60 (Fig. 3). The R^2 value of the model formed with 10 neurons (10N-ANN) was 0.72 (Fig. 4).

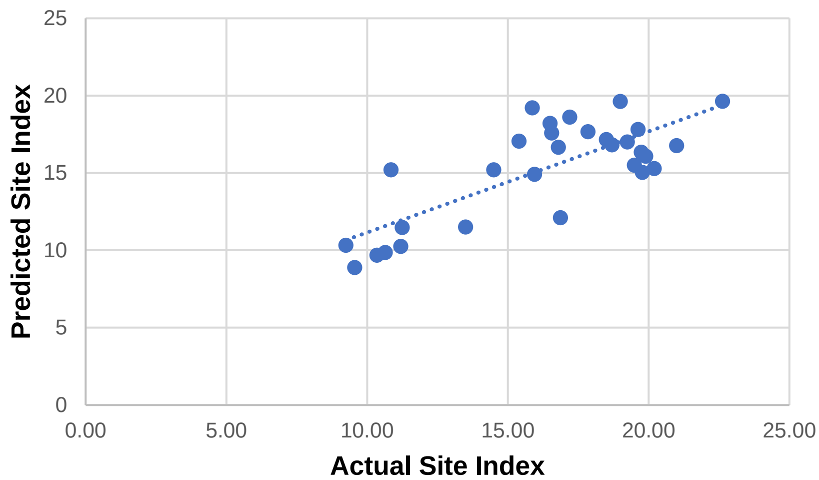

Fig. 3. Relationship of actual and predicted SI for 5N-ANN Model

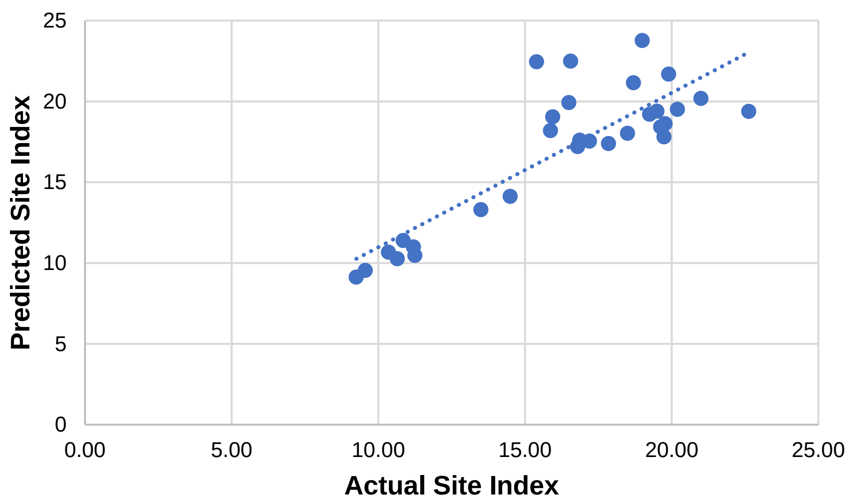

Fig. 4. Relationship of actual and predicted SI for 10N-ANN Model

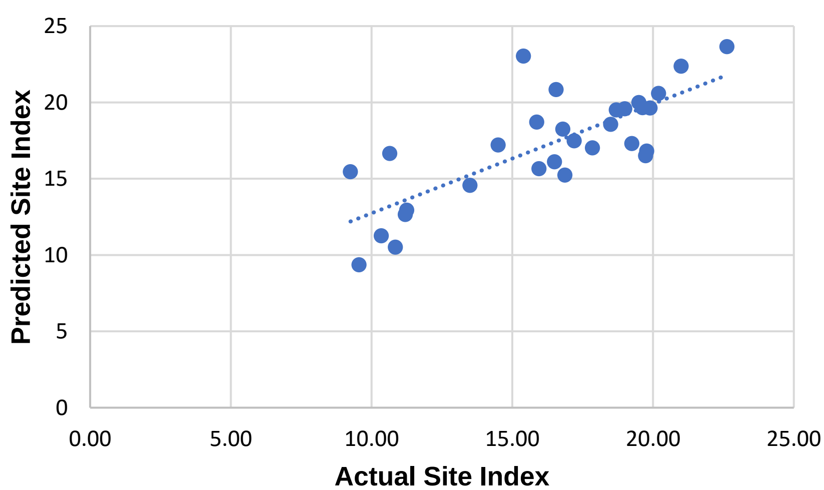

Fig. 5. Relationship of actual and predicted SI for 10N-ANN Model

The R^2 value of the model formed with 20 neurons (20N-ANN) was 0.59 (Fig. 5). The performance of the models formed is shown in Table 5. According to Table 5, the most accurate predictive model was the 10N-ANN model.

Table 5. Prediction Success of Created Models

Models	Regression Model	5N-ANN	10N-ANN	20N-ANN
n	120	30	30	30
R^2	0.22	0.60	0.72	0.59
MAD	0.96	2.09	1.51	1.78
MSE	3.34	6.69	5.48	6.89
RMSE	1.83	2.59	2.34	2.62
MAPE	6.73	12.54	8.92	12.66

Following the correlation analysis to investigate the bilateral relations of the habitat characteristics of black pine, because of a multi-connecting problem that might be caused by high correlation, the most representative variables among climatic variables were selected, and the number of independent variables was reduced from 29 to 12. As a result of the correlation analysis between site index and independent variables, statistically significant relations were determined between site index and total carbonate, pH, BIO7, and slope.

Multivariate statistical analyses were performed, after determining the bilateral relations. The wood production model was formed using the variables total carbonate (TC), pH, BI07, and Slope. These parameters had a significant relation with SI in multivariate statistical analyses. The predictive power of the model is 0.22. Equation 1 is expressed as follows:

$$SI = 41{,}615 + (\text{TC x } 0.119) + (\text{pH x } 0.286) - (\text{BIO7 x } 0.768) - (\text{Slope x } 0.188) \quad (1)$$

Coefficient of Determination (R^2), MAD, MSE, RMSE, and MAPE were used as standard statistical metrics to measure the model performance. In the modelling, three artificial neural network models with a high predictive power were formed. The models were made of 5, 10, and 20 neurons, respectively. It was found that the model with 10 neurons had the highest predictive power (R^2 = 0.72). To evaluate the models; the MAD, MSE, RMSE and MAPE metric values of the models were compared (Witt and Witt 1992). The model with 10 neurons had the lowest metric values (MAD = 1.51; MSE = 5.48; RMSE = 2.34, and MAPE = 8.92). As a result, site index was explained better by the independent variables in the model with 10 neurons, compared to other models. The relation between the site index and total carbonate, pH, BIO7, and Slope was statistically significant.

DISCUSSION

A high wood productivity of a forest site is regarded as desirable. In addition, a wide distribution of species can be regarded as a favorable attribute in natural forests. Starting from this point, different studies have been conducted to investigate the wood production of species and their habitat characteristics from the past to today (Ozkan 2004; Ozkan *et al.* 2008; Ozkan and Gulsoy 2009; Ozel *et al.* 2011; Guner *et al.* 2011). Each of these studies have introduced significant new information about the wood production of species. The present study also models the wood production of the species using multivariate analyses by identifying bilateral linear relations related to the species.

Soil pH (reaction) is a parameter that has a significant effect on the physical, chemical, and biological processes of soil, which has a direct effect on plant development. Plant development is closely related to soil pH. In all soil types, the dissolvability, mobility, and bioavailability of trace elements are strongly affected by pH. In strong acid or alkaline soils, useful forms of nutrients are reduced, which limits plant development. Although the tolerances of plants for extreme pH levels are different, many plants exhibit an optimum performance in the pH close to neutral (Lauchli and Grattan 2012). The acidification of soil reaction may also deteriorate other soil characteristics. It is thought that the positive relation between site index and pH level was a consequence of such a relationship in the study.

Calcium carbonate causes a significant amount of calcium to enter the soil. Because calcium is a nutrient of plants, it is effective both biochemically and functionally and has an important role in terms of the increment of the resistance of plants against stress conditions and in their development (Msimbira and Smith 2020). The positive relation between site index and calcium carbonate may result from this.

In the study, it is found that site index value decreases depending on the increase in annual temperature (BIO7). Aridity increases depending on the increase in temperature. Precipitation in an arid period has a vital importance for black pine, and it is expected that the wood production of black pine increases in parallel to the increase in precipitation. In terms of vegetation, the most striking characteristic of the Mediterranean climate is the persistence of dry conditions and low summer rainfall, as well as the high temperatures during this period. The severity and duration of summer aridness are of vital importance and are reported to affect plants strongly (Akman 2011). When considered that the changes in tree growth are controlled by the availability of water at a level of 85%, rainfall's importance has been clearly shown (Zahner 1968).

Aridness may decrease the increment of the biomass of plants by an average of 50%, and when it occurs during a long period, it may limit their natural distribution. It is reported in observations in Europe that aridness causes a 30% decrease in total forest production (Ciais *et al.* 2005). Similarly, there are reports of a 40% decrease in total wood production in forests due to drought (Tufekcioglu and Tufekcioglu 2018).

Site index decreases depending on the increase in slope. This may be because the surface flow increases as the slope increases. In addition, erosion intensity increases, the stoniness of soil increases, and soil depth decreases. Considering all of these factors, available water capacity decreases. Therefore, in areas with too much slope, there is arid and poor soil not suitable for water and nutrient economy (Oberhuber and Kofler 2000; Weber *et al.* 2007).

Slope is usually inversely correlated to soil depth (Ozkan and Kuzugudenli 2010). In other words, as slope increases, soil depth is expected to decrease. Soil depth affects soil volume in which tree roots can develop. Water is retained in the soil and soil nutrient capacity is associated with the soil amount. Therefore, studies have been conducted to reveal the SI relation between habitat characteristics and soil depth. In these studies, significant relations between SI and soil depth were found (Atasoy 1985; Dasdemir 1992; Gunlu *et al.* 2006).

Many studies have been carried out examining the relationship between slope and SI. In the studies conducted on *Pinus* species, a negative correlation between SI and slope was found (Cepel 1977; Zech and Cepel 1972; Eruz 1984). According to Kalay (1989), there is a significant negative correlation between slope and SI. This ecologically means that wood production decreases as the slope increases. In practice, forests in steep growth areas should be allocated as protection forests. In such areas, when forestry activities are not performed, expenses will be reduced (such as erosion and landslides) even if it causes a slight decrease in national wood production.

The ANNs and MRA methods were employed to model the SI of black pine. The ANN model with 10 neurons had the highest explanation power and the lowest error. The increase in the neuron number first increases the predictive power of the model up to a certain point and then it decreases (Table 5). In the formation of ANN models, usually, the trial-and-error method is used to determine the neuron number (Kaastra and Boyd 1996). Therefore, a linear relation between the neuron number and the success of the model was observed.

Likewise, Yadav and Chandel (2014) studied solar irradiance using air temperature and sunshine duration factors in regression and ANN models. Tokar and Johnson (1999) performed a study to forecast flow rate (daily) using several habitat parameters in regression and ANN models. They compared regression models and ANN and found that the performance values of ANN models were improved compared with those of the regression models. Kumar *et al.* (2015) also conducted a study to measure solar radiation by employing certain parameters in regression and the ANN model. Again, the values obtained using artificial neural network models outperformed the values obtained using regression models. Kuzugudenli (2018) used the factors of average temperature, total precipitation, and altitude parameters to predict relative humidity *via* ANN and regression models. The ANN's performance was also better than the performance of the regression model. Kuzugudenli and Kaya (2020) were other researchers who used ANN and regression models to predict SI through several topographic factors. In that study, the ANN model also exhibited a better performance when compared to the regression model. Consequently, in all these studies, ANN models performed better than regression models as in the present study.

CONCLUSIONS

1. The use of the 10N-ANN model obtained as a result of the study for the highest wood production in sites where the study was conducted, and similar growth sites is of high importance for the success of wood production.
2. ANN, which is a more powerful alternative than linear regression modelling in which the prediction success is lower, is preferred because it can successfully model complex relations and does not require the satisfactions of some assumptions as other statistical methods.
3. If data number is increased by including different stands in the study in the prediction of wood production, and input number is increased by adding other variables related to wood production to the model, the prediction success of ANN can be increased.
4. No earthquake-related damage was observed in the sample areas.

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