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MODELING SITE PRODUCTIVITY OF ANATOLIAN BLACK PINE STANDS IN RESPONSE TO SITE FACTORS IN BULDAN DISTRICT, TURKEY

SERKAN GULSOY[1]*, HALIL SUEL[2], HALIL CELIK[3], SERKAN OZDEMIR[1] AND KURSAD OZKAN[1]

[1]*Suleyman Demirel University, Faulty of Forestry, Department of Forest Engineering, 32260, Isparta, Turkey*
[2]*Suleyman Demirel University, Sutculer Vocational School, 32950, Sutculer, Isparta, Turkey*
[3]*Akdeniz University, Akseki Vocational School, 07630, Akseki, Antalya, Turkey*
**Corresponding author's e-mail: srkngulsoy@gmail.com*

Abstract

This study was performed to determine modeling height growth of Anatolian black pine (*Pinusnigra* Arn. ssp. *pallasiana* (Lamb.) Holmboe) stands according to the site factors in the Buldan forest district. Site index and environmental data obtained from 19 sample plots in the district were fitted by Stepwise Multiple Regression Analysis (SMRA) and Regression Tree (RT) using SPSS 17.0 and DTREG softwares. Schist structured quartzites, slope position and clay percent of B horizon (R^2 =0,67) were determined as the most significant variables for the model obtained from SMRA. Two different models were determined by RT statistics. The first one was represented by slope position and altitude (R^2 =0,67), while slope position and surface stoniness were the most important variables in the second model and prediction values of site index were separately calculated by all these models. Consequently, R^2 =0,84 was the most significance level when theaverage of these prediction values correlated with the actual site index values.

Introduction

Black pine is a typical Southern European tree species, with a distribution between 05°-40°E longitude and 35°-48° N latitude (Critchfield & Little, 1966; Davis, 1985). Within this distribution range, it is most widely distributed within Spain, the Balkans and Turkey. It also occurs in France, Morocco, Italy, Corsica, Austria, Yugoslavia, Crimea, North Cyprus and Syria (Critchfield & Little 1966; Yucel, 1995; Yucel & Ozturk, 2000). Black pine occurs in various ecotypes and 6 main subspecies globally (ssp. *pallasiana,* ssp. *fenzlii,* ssp. *dalmatica,* ssp. *nigra,* ssp. *laricio,*and ssp. salzmannii) (Schwarz, 1938). Among these subspecies, *Pinusnigra* Arnold. subsp. *pallasiana* (Lamb) Halmboe is indigenous to Turkey, where it is known as "Anatolian black pine".

Recent studies reported that the total forestry land in Turkey is 21.5 million ha (Anon., 2011). After Red pine (*Pinusbrutia* Ten.), Anatolian black pine has the second-greatest coverage at 4.2 million ha, and ranks first in terms of total commercial value. Coniferous species comprise 13.1 million ha of all Turkish forest areas, and it is reported that within this area, an average of 1.7 million ha of land is classified as degraded forests (Anon., 2011). Naturally, majority of these degraded forest areas consist of black pine stands. Therefore, it is very important to manage productivity of the areas for Anatolian black pine, which is of great importance for Turkey ecologically and economically. This should be achieved within the framework of sustainable forestry perception and should aim to make degraded areas productive.

Due to the importance of black pine, many studies have been conducted on a variety of subjects related to this species (Alptekin, 1986; Genc *et al.,* 1999; Guner, 2001; Carus, 2005; Yucel, 2008; Genc *et al.,* 2012; Keskin & Ili, 2012; Nazir & Khan, 2013). Eruz (1984) has studied the relationship between height growth of the species and its edaphic and physiographical features as a pioneering study in this field. Subsequently, Yucel (1995) has conducted a multidimensional study on morphology, natural distribution, climate and nutritional relationships, soil and litter characteristics, root structure, germination and growing characteristics of black pine. Yucel (2000) investigated ecological and morphological features of Ebe black pine. In another study on the ecology of the species, Ozkan (2004) investigated the relationship between distribution of black pine in the Beyşehir Lake basin and physiological site factors. Sevgi & Tecimen (2009) investigated physical, chemical and pedogenetical features of soils in relation to altitude at Kazdagi upland black pine forests. More recently, studies on the productivity of the species were conducted by Ozkan & Gulsoy (2009) in Sütçüler (Isparta) district, and by Guner *et al.,* (2011a) in Eskişehir & Afyonkarahisar provinces. A further remarkable study by Guner *et al.,* (2011b) identified woody indicator species of potential distribution areas where the species can be productive.

There is no doubt that all these studies on this species are very important. However these studies are not enough, considering the importance of this species. Environmental factors such as geomorphology, topography, edaphology and climate show great regional variations, especially in Turkey. This significantly affects the productivity of tree species in the forests. Therefore, the relationship between productivity of species and forest site factors should be investigated locally and regionally. This study aims to model productivity of Anatolian black pine according to forest site factors of Buldan district, which represents the West Mediterranean region where the species has a significant distribution.

Materials and Methods

Site description: This study was conducted in black pine forests in Buldan district, northwest Denizli province, located in the southwest of Turkey (longitude 28°38′-28°51′E, latitude 37°59′–38°04′N (Fig. 1). The districts of Kuyucak, Güney, Sarigöl & Sarayköy are located in the west, east, north and south of Buldan, respectively. The Çayır and Kestane streams are fed from high mountains in the district, and merge to feed the Buldan stream which joins the Büyük Menderes river (Cukurluoglu & Bacanli, 2006). Yayla (Süleymanli) Lake is located on Sazak plain (466 decares, altitude 1150 m) in the north of the district, and is of great importance for various plant and bird species as well as local climate. In addition, the Derbent dam is an important water source for irrigation in the district.

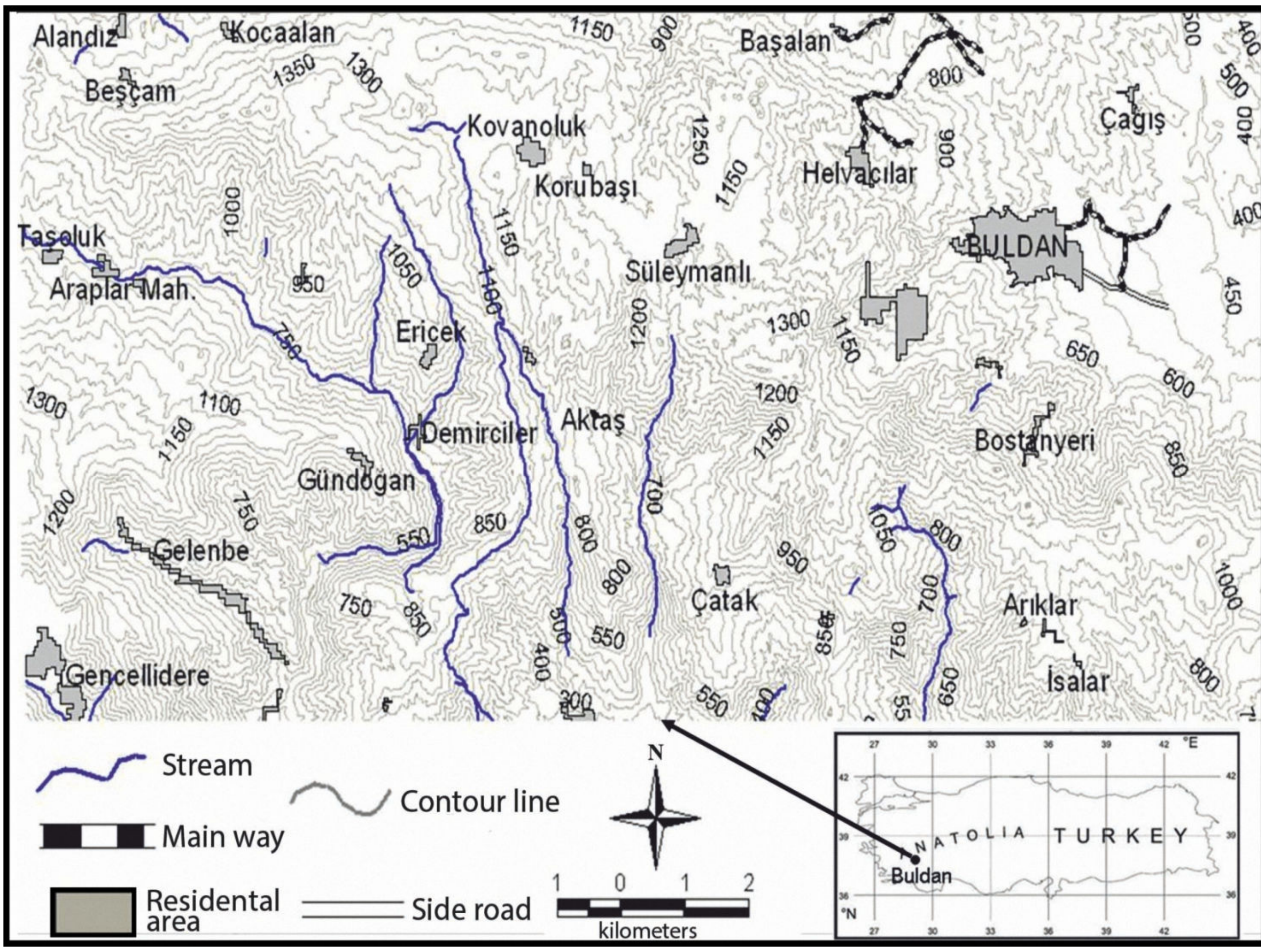

Fig. 1. Site location map of Buldan district, Turkey.

Multiyear climate data for covering 15 years from Turkish State Meteorological Service shows that the district is located in a transition zone between typical Mediterranean and continental climates, with dry and hot summers and cold wet winters (Anon., 2003). Measurements performed at approximately 610m altitude show that mean monthly temperature is between 9.48°C (January) and 33.2°C (August), and mean annual rainfall is approximately 650 mm (Table 1). The data was evaluated according to rainfall effectiveness indices.

$$\text{Im} = \frac{100s - 60d}{n}$$

using Thornthwaite method. Where;
s: annual water surplus,
d: annual water deficit,
n: annual evapotranspiration

The results indicate that the district is located within a semi humid–dry climate class (Cepel, 1995; Ozyuvaci, 1999).

In addition, Fig. 2 shows that the dry summer begins in June and continues for approximately 4 months until the mid-September (Fig. 2).

There are many different types of bedrocks in the district, most common being Precambrian aged gneiss (approximately 60%). In these areas, soil depth differs and land surface is generally plain or slightly rough. Physiological depth is high in gneissic areas, due to the cracked form of the bedrock (Ozkan & Gulsoy, 2010).

Pedogenesis occurs gradually in areas where Paleozoic aged schist structured quartzite occurs as bedrock; thus, such areas have shallow or very shallow pedogenesis. On the other hand, some parts of the district include bedrock formations with sandstone at the top and clay stone at the bottom, which are young Pliocene sedimentary materials. These areas have clayey and deep soil types with variable slope and plain land surfaces. Old Quaternary alluviums are particularly prevalent in the center of Buldan and around Süleymanlı. These areas are generally plain and have deep or very deep soils. Old Ordovician metagranite has a cracked form and the depth of soils over this bedrock varies from very shallow to moderately deep. Other notable bedrock formations include old Sub-Miocene granites in the northwest of the region and old Precambrian migmatiticpelitic gneiss between Süleymanlı & Demirciler (Ozkan *et al.,* 2006).

In terms of phytogeographical regions, the study area comprises Mediterranean element plant species and also, because it is located in a transition zone, plant species of Euro-Siberian and Irano-Turanian elements. The study area includes important plant families like *Compositae, Fabaceae, Poaceae, Labiatae, Brassicaceae, Caryophyllaceae, Umbelliferae, Liliaceae* and *Boraginaceae*, of which the family *Compositae* has the largest number of species. The most common genera are *Trifolium, Anthemis, Vicia, Galium, Bromus, Rumex,* *Centaurea, Ranunculus, Lathyrus* and *Silene*, (Celik *et al.,* 2006). The rate of endemism among these families is around 9 percent, which is low compared to the 31percent endemism rate for Turkey. In the study area, red pine *(Pinusbrutia* Ten.*)* and black pine *(Pinusnigra* Arnold*)* are essential forest tree species, forming forests in the widest sense. Apart from these species, stone pine (*Pinuspinea* L.), Turkey oak (*Quercuscerris* L.), Gall oak (*Quercus infectoria* Olivier.) and Anatolian valonia oak (*Quercus ithaburensis* Decn.) partly merge with red pine and black pine and are also distributed as small stands (Ozkan *et al.,* 2006).

Field sampling and laboratory methods: The study was conducted in a total of 19 black pine stands at elevations of 920-1300 m in Buldan district. 400 m^2 sample plots were selected and the heights of three plus trees were measured at each plot. Various physiographical site factors and edaphic factors of the plots were recorded. Physiographical site factors comprised: height (m), slope degree (%), surface stoniness (%), slope position, aspect, surface roughness and surface form. Soil characteristics comprised: stone percentages in horizons and total soil depth (cm). During land inventory studies, soil samples were taken and soil profiles were defined in accordance with the proper method and soil samples were taken from Ah, Bv and Cv horizons (Anon., 1951). In addition, bedrock samples were taken and identified from each sample area.

Soil samples were transferred to the laboratory in plastic containers after field studies. Air dried samples were then ground and sifted through 2-mm sieves prior to analysis. The hydrometer method was used to determine soil texture (Bouyoucos, 1962); a glass electrode pH meter was used in 1:1 soil-water and 1:1 1 N-KCI mixtures for pH values (Jackson, 1958). The volumetric method was used with a Schleiblercalcimeter for lime content (Allison & Moodie, 1965). Soil salinity (EC) was determined via a conductivity device in saturated soil extract; and a revised Walkley–Black wet decomposition method was used to identify organic substances and measure electrical conductivity (Walkley & Black, 1934). In addition, a pressure sheet device was used for soil samples with farm capacity < 33 kPa and 1500 kPa wilting point, and utilizable water capacity was calculated according to the difference between the two values (Klute, 1986). These methods are outlined in detail in Ozturk *et al.,* (1997).

Table 1. Water balance model of Denizli-Buldan district (based on rainfall effectiveness by Thornthwaite method).

Balance sheet elements	Months												Annual
	J	F	M	A	M	J	J	A	S	O	N	D	
Mean monthly temperature	9.48	10.51	14.31	19.98	24.24	29.18	33.11	33.2	28.63	21.64	14.68	10.3	20.77
Temperature Index	2.63	3.08	4.9	8.14	10.91	14.45	17.50	17.57	14.04	9.19	5.11	2.99	110.53
Uncorrected PE	10.0	13.0	28.2	65.4	106.4	156.2	177.4	177.7	152.1	80.0	30.1	12.4	
Corrected PE	8.5	10.9	29.1	72.1	130.4	192.8	222.0	208.2	157.4	77.0	25.4	10.2	1143.9
Monthly precipitation	126.4	76.6	70.4	39.9	35.0	12.8	15.1	9.4	8.5	25.0	94.6	135.3	649.2
Storechange	0.0	0.0	0.0	32.1	67.9	0.0	0.0	0.0	0.0	0.0	69.3	30.7	
Storage	100.0	100.0	100.0	67.9	0.0	0.0	0.0	0.0	0.0	0.0	69.3	100.0	
Actuale vapotranspiration	8.5	10.9	29.1	72.1	102.9	12.8	15.1	9.4	8.5	25.0	25.4	10.2	329.8
Water deficiency	0.0	0.0	0.0	0.0	27.5	180.1	206.9	198.7	148.9	52.0	0.0	0.0	814.1
Water surplus	117.9	65.7	41.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.4	319.4
Surface flow	106.2	91.8	53.5	20.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.2	319.4
Humidity rate	13.8	6.0	1.4	-0.4	-0.7	-0.9	-0.9	-1.0	-0.9	-0.7	2.7	12.3	
s= 319.18 cm	*d*= 815.00 cm				*n*= 1144.82 cm				*Im* (HumidityIndicator) = -14.83				

Semi humid–dry climate class

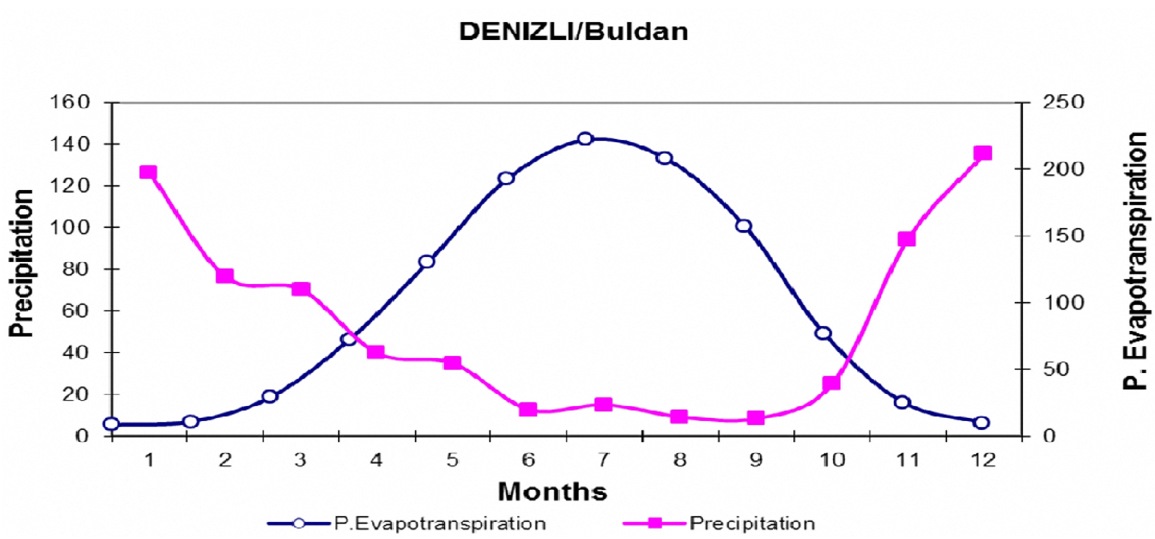

Fig. 2. Water balance chart for Denizli-Buldan District according to Thornthwaite method.

Table 2. Variables obtained from the field and laboratory studies and pre-statistical assessment codes.

Codes	Variebles	Codes	Variebles
SI	Site index (100 age)	Ahwatr	Ah horizon available water capacity (%)
altitu	Altitude (m)	Bvstne	Bv horizon stoniness (%)
slope	Slope (%)	Bvcaco	Bv total calcium carbonate (%)
sdepth	Soil depth (cm)	Bvorgm	Bv horizon organic matter (%)
slppos	Slope (landscape) position	Bvph	Bv horizon soil pH
aspect	Aspect	Bvec	Bv horizon electrical conductivity (μ)
fstoni	Field surface stoniness (%)	Bvclay	Bv horizon clay (%)
srfrgh	Field surface roughness	Bvdust	Bv horizon dust (%)
litthc	Litter thickness (cm)	Bvsand	Bv horizon sand (%)
lndfrm	Landform type	Bvfcap	Bvhorizon field capacity (%)
gneiss	Precambrian aged gneiss	Bvwilt	Bv horizon permanent wilting capacity (%)
sndcly	Pliocene aged sandstone-claystone deposits	Bvwatr	Bv horizon available water capacity (%)
quartz	Paleozoic schist structured quartzite	Cvstne	Bv horizon stoniness (%)
aluvil	Quaternary alluvial deposits	Cvcaco	Cv total calcium carbonate (%)
Ahstne	Ah horizon stoniness (%)	Cvorgm	Cv horizon organic matter (%)
Ahcaco	Ah total calcium carbonate (%)	Cvph	Cv horizon soil pH
Ahorgm	Ah horizon organic matter (%)	Cvec	Cv horizon electrical conductivity (μ)
Ahph	Ah horizon soil pH	Cvclay	Cv horizon clay (%)
Ahec	Ah horizon electrical conductivity (μ)	Cvdust	Cv horizon dust (%)
Ahclay	Ah horizon clay (%)	Cvsand	Cv horizon sand (%)
Ahdust	Ah horizon dust (%)	Cvfcap	Cvhorizon field capacity (%)
Ahsand	Ah horizon sand (%)	Cvwilt	Cv horizon permanent wilting capacity (%)
Ahfcap	Ah horizon field capacity (%)	Cvwatr	Cv horizon available water capacity (%)
Ahwilt	Ah horizon permanent wilting capacity (%)		

Statistical analysis: A total of 47 variables including top height measurements of the plus trees in the plots were recorded after the field and laboratory studies. Before the statistical assessment, top height measurements (obtained from land measurements by means of site index (SI) tables developed by Kalipsiz (1963) were indexed to 100 years.

Slope position, aspect, surface roughness, surface form and bedrock variables could not be obtained numerically. These variables were recorded as categorical data before statistical assessments. Slope position was classified as; 1 (hill), 2 (upper slope), 3 (middle slope), 4 (lower slope) and 5 (bottom land). Surface roughness was classified as 1 for plain areas, 2 for rough areas. Surface form was classified as 1 (undulate), 2 (convex) and 3 (concave). Aspect was classified as 1 (north), 2 (northeast and northwest), 3 (east and west), 4 (southeast and southwest) and 5 (south).

When classifying sample plots according to bedrock types, presence/absence data of gneisses, quartzites, sandstone-claystone ordering and alluvial areas were recorded as four different variables. All data were encoded before statistical assessment and stored in Microsoft Excel according to sample field numbers (Table 2).

Pearson correlation (for continuous data) and Spearman correlation (for categorical and presence/absence data) analyses were performed to detect whether there was a relationship between SI values and the 46 independent variables. Stepwise multiple regression analysis (SMRA) in SPSS 17.0 and regression tree (RT) statistics by using DTREG package program were performed to evaluate relationships between all independent variables and SIvalues. Models were thereby developed to represent the SIvalues for black pine in the district. In addition, SIprediction values were calculated according to the models and simple linear regression analysis was used to reveal the significance level of the relationship between actual and predicted SIvalues (Ozdamar, 1999).

Results

The heights of the selected three plus trees in each sample plot were indexed to 100 years and averaged. Accordingly, it was found that the SI values in the field study range between 17.6 m and 34.8 m. Correlation analysis results showed that SI values were significantly positively related to slope position; but significantly negatively related to stone percentage of Ah horizon and Paleozoic aged schist structured quartzites (Tables 3, 4).

Table 3. Results of spearman's rank correlation analysis.

	SI			SI	
slppos	R	***0,463****	gneiss	r	0,289 NS
	P	***0,046***		p	0,231
aspect	R	-0,355 NS	quartz	r	***-0,676*****
	P	0,136		p	***0,001***
srfrgh	R	-0,422 NS	aluvil	r	0,215 NS
	P	0,072		p	0,376
lndfrm	R	-0,315 NS	sndcly	r	0,290 NS
	P	0,189		p	0,229

NS: Non-significant * Significant at the 0.05 level, ** Significant at the 0.01 level, *** Significant at the 0.001 level

Table 4. Results of pearson rank correlation analysis.

	SI			SI	
altitu	r	-0,016 NS	Bvorgm	r	-0,136 NS
	p	0,948		p	0,579
slope	r	-0,061 NS	Bvph	r	0,250 NS
	p	0,804		p	0,302
sdepth	r	0,191 NS	Bvec	r	0,162 NS
	p	0,434		p	0,508
fstoni	r	-0,431 NS	Bvclay	r	0,321 NS
	p	0,066		p	0,181
litthc	r	0,202 NS	Bvdust	r	0,182 NS
	p	0,407		p	0,455
Ahstne	r	***-0,478****	Bvsand	r	-0,268 NS
	p	***0,038***		p	0,267
Bvstne	r	-0,188 NS	Bvfcap	r	0,195 NS
	p	0,441		p	0,423
Cvstne	r	-0,281 NS	Bvwilt	r	0,298 NS
	p	0,243		p	0,216
Ahcaco	r	0,124 NS	Bvwatr	r	-0,014 NS
	p	0,612		p	0,954
Ahorgm	r	-0,333 NS	Cvcaco	r	0,294 NS
	p	0,164		p	0,223
Ahph	r	0,148 NS	Cvorgm	r	-0,016 NS
	p	0,545		p	0,948
Ahec	r	0,214 NS	Cvph	r	0,266 NS
	p	0,379		p	0,270
Ahclay	r	0,175 NS	Cvec	r	0,197 NS
	p	0,473		p	0,419
Ahdust	r	0,038 NS	Cvclay	r	0,292 NS
	p	0,876		p	0,225
Ahsand	r	-0,131 NS	Cvdust	r	0,111 NS
	p	0,594		p	0,650
Ahfcap	r	0,093 NS	Cvsand	r	-0,233 NS
	p	0,706		p	0,338
Ahwilt	r	0,225 NS	Cvfcap	r	0,211 NS
	p	0,355		p	0,386
Ahwatr	r	-0,138 NS	Cvwilt	r	0,257 NS
	p	0,574		p	0,288
Bvcaco	r	0,255 NS	Cvwatr	r	0,132 NS
	p	0,292		p	0,589

NS: Non-significant * Significant at the 0.05 level, ** Significant at the 0.01 level, *** Significant at the 0.001 level

After the detection of bilateral relationships between SI values and independent variables, SMRA and RT statistics were used to identify the most appropriate model to represent black pine height growth by means of independent variables.

Three different models were obtained from the stepwise multiple regression analysis (SMRA) (Table 5). In the third model, it can be seen that the highest R^2 value (0.668) was obtained for Paleozoic aged schist structured quartzites, slope position and clay percentage of Bc horizon.

Table 5. Models obtained from the multiple regression analysis (MRA).

Models	R^2	p (Models)	Variables in Models		p (Variebles)	VIF
1	0,341	0,009	Constant	27,755	0,000	-
			quartz	-6,599	0,009	1,000
2	0,527	0,002	Constant	22,373	0,000	-
			quartz	-5,854	0,009	1,023
			slppos	1,932	0,023	1,023
3	0,668	0,001	Constant	17,640	0,000	-
			quartz	-4,642	0,019	1,105
			slppos	2,550	0,003	1,162
			Bvclay	0,285	0,024	1,189

Table 6. Actual and prediction values of the bonitet and average bonitet prediction values of the models.

Actual SI values	Pred. values of SMRA model	Pred. values of RT model (slppos-fstoni)	Pred. values of RT model (slppos-altitu)	Averages of pred. values of the models
34,82	31,94	31,61	31,61	31,72
27,63	29,39	26,43	22,13	25,99
17,58	17,94	19,67	22,13	19,91
20,02	21,56	19,67	22,13	21,12
24,27	23,44	26,44	22,13	24,00
20,41	24,79	19,67	22,13	22,20
33,96	28,18	31,61	31,61	30,47
19,91	21,90	19,67	22,13	21,23
29,81	31,47	31,61	31,61	31,57
25,86	29,09	31,61	31,61	30,77
26,75	22,19	26,44	27,42	25,35
28,53	30,26	26,44	27,42	28,04
24,97	27,11	26,44	22,13	25,23
20,42	24,42	19,67	22,13	22,07
31,64	31,18	26,44	27,42	28,34
33,61	30,03	31,61	31,61	31,09
25,27	23,04	26,44	27,42	25,63
24,89	25,50	26,44	27,42	26,45
24,00	20,95	26,44	22,13	23,17

Two different models were obtained from the regression tree (RT) statistics. The first model consists of slope position and altitude, while the second consists of slope position and stone percentage of surface (Fig. 3). R^2 values for these models were 0.764 and 0.641 respectively.

Instead of choosing one model to predict site index of Anatolian black pine, we preferred to calculate average predicted values (APV) of all models (Table 6) and, compare to APV obtained from those models with actual values of site index due to the fact that all the models showed good results. On this context, firstly the average predicted values (APV) of the best SMRA model and two RT modelswere calculated. Next a regression analysis was applied between PAV and actual site index values. As a result, it was found a very high R^2 value of 0.840 (Fig. 4).

Discussion

The findings show that the forest site factors most influential on the height growth of black pine in Buldan district are slope position, stone percentage of Ah horizon and Paleozoic aged schist structured quartzites. It was found that SI tends to increase from ridge areas to bottom hillside. In parallel with the results of this study, Eruz (1984) reported that going from top hillside to lower slope positions and bottom land, was associated with increased SI. Similar results related to slope position and height growth of species have been reported by Zech & Cepel (1972), in their study conducted in red pine forests of the Regional Directorate of Forestry; and by Cepel & Dündar (1980), in their study on yellow pine stand of Bolu-Aladağ. It is assumed that this similarity is because sub-lands provide more suitable conditions for plants, with greater availability of soil, water and nutrients (Guner *et al.,* 2011a).

The results reveal a negative correlation between height growth of black pine and Paleozoic aged schist structured quartzites. In other words, SI values of black pine decreases significantly in sample areas comprising quartzite bedrock. Quartzites are nonporous rocks which have got metamorphosed due to the compression of sandstones and conglomerates. Areas with quartzite bedrock are generally steep and rocky, with shallow and nutrient-poor soils. Therefore, the low productivity of black pine forests on this bedrock is due to the effect of bedrock on various physical and chemical characteristics of the soil. Kantarci (2000) has reported that schist structured quartzite soils are fine, sand-rich and nutrient-poor, and thus provide poor conditions for plant growth.

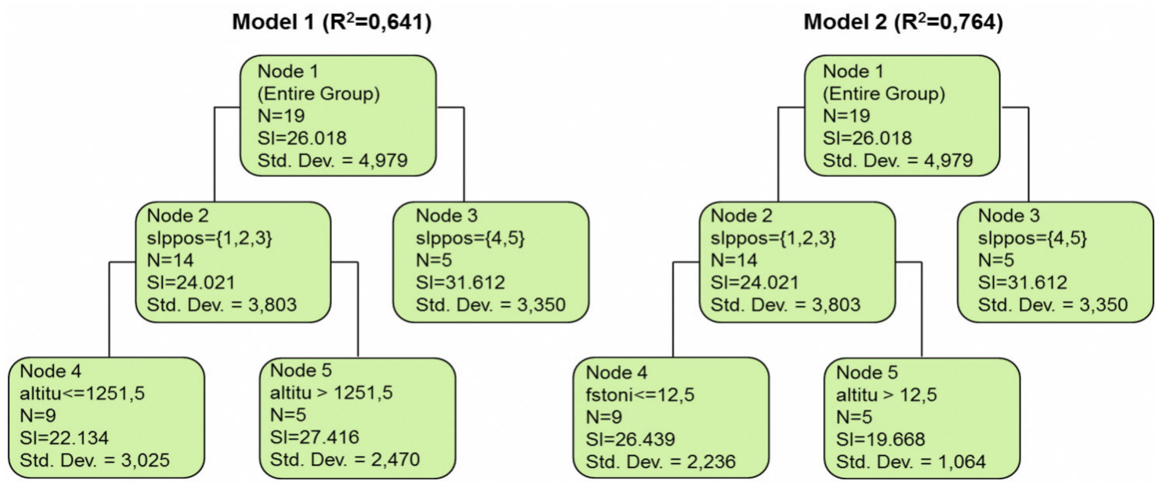

Fig. 3. Variables of models obtained from the regression tree statistics.

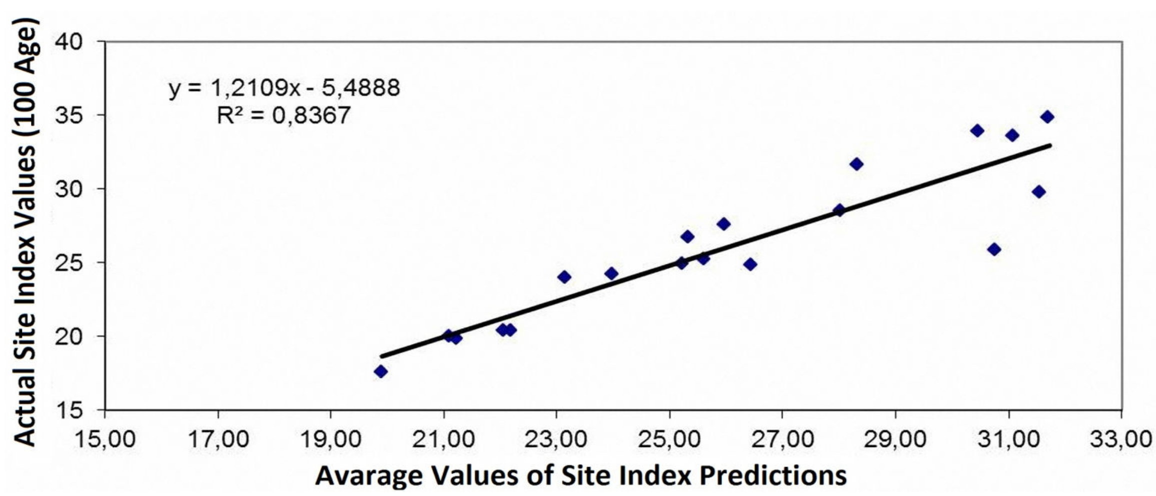

Fig. 4. Results of simple linear regression analysis between model prediction and observed SI values.

On the other hand, the correlation analysis indicated that SI decreases inversely in proportion to the percentage of stones in the Ah horizon. This may result from the high percentages of stones present in shallow soils formed on schist structured quartzites.

In addition to identifying relationships between variables, models were obtained for the height growth of black pine. Stepwise multiple regression analysis produced three different models for black pine; the relationship coefficient (R^2 = 0.67) of the third model was found to be especially high. The model was totally represented by three different variables including B horizon clay percentage in addition to the variables of schist structured quartzites and slope position obtained from the correlation analysis. Therefore, the potential model to predict heights of black pine aged 100 in regeneration activities within similar site conditions to Buldan district is as follows:

$$H_{100}= (17.640) + (-4.642^* \text{ schist structured quartzite}) + (2.550^*\text{slope position}) + (0.285^*\text{B horizon clay percentage})$$

Two different models were obtained from the regression tree statistics. The first consisted of slope position and altitude and the second one of slope position and surface stone percentage. The explanation coefficient of the second model was particularly high (R2=0.764) (Fig. 3). Therefore, we can say that variables in this model can provide information on the subsequent black pine afforestation efforts in the district. As slope position is particularly influential in both correlation analysis and all models, it represents a key factor for planting activities in the district.

Regarding the relationship coefficient between the mean of predicted SI values obtained with stepwise multiple regression and regression tree models, the observed site index values were particularly high, at 84% (Fig. 4). This is also an indicator of the usability of these models in the district.

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