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Some bark characteristics of Black Pine (*Pinus nigra* arnold.) and their variation throughout the tree height

Orhan Sevgi[1]*, Hüseyin Barış Tecimen[1], Serdar Carus[2], Serdar Akburak[1] and Engin Çakşir[3]
[1]Istanbul University, Faculty of Forestry, Department of Soil Science and Ecology, TR-34 473 Bahçeköy-Istanbul, Turkey
[2]Süleyman Demirel University, Faculty of Forestry Dendrometry and Yield Department -Isparta, 32 260, Turkey
[3]Forest General Directorate, Yalova Forest Interpretation Directorate, Yalova, 77 200, Turkey
*Corresponding Author E-mail: **osevgi@istanbul.edu.tr**

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Abstract

The sampled trees were selected from woodlands in the Alaçam Mountains located between Balıkesir and Kütahya provinces. Study was conducted on the bark samples of cross-sections taken from 2 ± 0.05 m sections of totally 20 trees and each tree were taken from different sites. 222 tree sections were obtained to be sampled. pH, weight and total nitrogen content of bark samples were determined. Total nitrogen content of tree trunk bark was calculated by multiplying nitrogen content of bark by bark weight. It was determined that bark pH increased depending on the section height and its weight decreased, however, nitrogen % value increased. R^2 values of linear equations that were established using section height in single trees varied between 0.45 and 0.91 ($p<0,05$). It was found that even though thick and woody bark residues provided a high amount of raw material to be decomposed and/or be a nest for microfauna, the formed fresh bark had more alkali content and had higher potential to be the nitrogen source for forest ecosystems.

Key words

Bark, Forest ecosystem, *Pinus nigra*, Section height

Introduction

Bark, that forms the outer covering of trees, is susceptible to external influences. Protection of cambium cells is one of the important functions of bark in terms of tree health. This protective function shows itself in the form of protection from cold weather in winter and hot temperatures in summer (Wesolowski *et al.,* 2014). Directly engaging in assimilation activities, barks of some trees help with growth and increment (Covington, 1975). In trees, bark plays a role in the transport of many nutrients and compounds. It is also important in terms of gas exchange in the secondary phloem (Yentür, 2003).

Beside the importance of bark to trees, it also has significant functions for forest ecosystems. Water-holding properties of the barks, accordingly, make direct contribution to water cycle and determination of ecosystem water budgets (Çepel, 1993; Levia and Herwitz, 2005). Since they provide direct habitat to epiphytic creatures, bark increases the species diversity of forest ecosystems in which they live (Barkmann, 1958).

Following the stem, bark mass is an important source of organic matter in forests (Patrick and Smith, 2009). Therefore, it serves as an important food source for the ecosystem. It is also considered as one of the forest products. In some countries, bark is used as a raw material source for various industries (Borchert, R., 1994), like, in the production of wood particleboard and fibreboard (Kantay and Köse, 2006).

As barks are indicator of pollutants on ecosystems, they are subjected to long-term monitoring (Yuan-wen *et al.,* 2006). They are used to monitor heavy metals in the air (Catinon *et al.*, 2009, Ribe *et al.*, 2009). Also, in recent years, the relationship between bark thickness and habitat productivity are being investigated. Thus, bark thickness has been tried to be shown as productivity index. In this regard, some studies were carried out on beech (Carus, 1998; Atıcı, 2009) and fir species (Saraçoglu, 1988). Also, diameter - double bark thickness is related to the productivity (Yıldızbak and Saraçoglu, 2004).

Black pine has 5 subspecies, *Pinus nigra* subsp. *lariocio*, *Pinus nigra* subsp. *salzmannii*, *Pinus nigra* subsp. *dalmatica*, *Pinus nigra* subsp. *nigra* and *Pinus nigra* subsp. *pallasiana* have an important distribution in the world (Barbero et. al. 1998; Bussotti, 2002). In addition to its natural distribution in Mediterranean region and Central Europe, Black pine has natural distribution in the countries like Belgium, Germany, Ireland, Finland, the UK, South Africa, Canada, USA and New Zealand and it is again a preferred species for forestation in the same countries (Bussotti, 2002). However, the majority of the range lies in Turkey (Akkemik, 2014).

Although barks have significant distribution and area of use, chemical properties of Black pine barks and their contribution to nutrient cycle in forest ecosystems are not adequately presented in the literature. The objective of the present study focused on thickness, quantity, pH and nitrogen content of Black pine barks, and their variation throughout the tree height was further analysed.

Materials and Methods

Habitat features : The study was carried out in Alaçam Mountains that lie on the provincial borders of Balıkesir and Kütahya (29° 15' 30" - 28° 15' 00" and 39° 15' 30" - 28° 15' 00"). Throughout the study area, water deficit begins in June and lasts in five months including October (Sevgi *et al.*, 2006). In the study area, the main parent rocks are Civana tuff, Eğrigöz Granite, Dasit, Dağardı Melange and Simav Metamorphite (Kütahya J22a,d, 21b,c,d Geological Map Sheet). Mountains in the study area are; Akdag, Ulus Mountain, Egrigöz and Alaçam Mountains. According to the present land surface properties; the study area can be defined as Medium Mountainous Terrain. In the study area, Black pine forms single-storey pure stand cover an area of 91 744 ha; notwithstanding, it forms two-layered pure stands whose area is a total of 14 722 ha (Sevgi *et al.*, 2006). Sample trees subjected to the study are taken from Alaçam Mountains where Black Pine has optimum habitat characteristic (Table 1). Including one sample tree from top height representing the sample area, a total of 20 trees were felled and sampled. On the trees, bark samples from the parts of 2±0.05 meter were taken. Section height and their barked diameters were measured. Of the sampled trees, ages vary between 26 and 210; heights between 8.1 m and 27.0 m and breast height diameters (1.30m) between 11.8 and 37.7 cm (Table 1).

Laboratory analysis : Determination of bark pH; having been treated with 1:10 distilled water, the bark was steeped for 24 hrs and measured by pH meter. If sample bark amount is 1.5 g, the solution was used by adding distilled water at the rate of 15 ml or multiples thereof (Herk, 2001). Total nitrogen content of the barks was determined by Kjheldahl method (Bremner and Mulvaney 1982). Total nitrogen content of the barks was determined at Buchi Auto Kjheldahl Unit K-370 device.

Aiming at the determination of bark thickness and weight, the trees were cut at the bottom and the stem was divided into parts of 0.3m, 1.3m and 2 m and sections were taken. Then, the bark thickness was measured in the micron scale by digital calliper; and thickness of each section was measured from 8 directions. Also, the samples were brought into oven dry weight at 65 °C and weighed on precise balance. Weighing result was divided by the section thickness and the weight corresponding to 1 cm rise throughout the trunk was stated in grams.

Statistical analysis methods : For the variables of sampled trees, linear regression models were created. Using all the data for each variable, being brought into association with the section height, equations were generated and error values of the estimates were given (Kalıpsız 1981; Özdamar, 2002). The abbreviations in the linear regression equations that are; Bark diameter (BD) and section height (SH) were assigned as dependent variants and bark reaction (pH) (BR), bark thickness (BT), bark nitrogen content (%) (BNC) and bark weight (BW) were assigned as independent variants. Analyses were executed at SPSS v18 program.

Results and Discussion

Bark pH values and their change throughout the tree height : pH values of Black pine barks ranged from 3.224 to 4.759 (Fig. 1a). Pearson's correlation coefficient between pH of 222 pieces Black pine barks of which pH values were determined within the scope of study and section height was 0.458 and significance level was 0.001. R^2 of the aforesaid equation was 0.21, its significance level was 0.001 and error margin of estimate was 0.262, consequently, the established model was; BR= 3.722 + (0.021*SH). As the section height increased, pH values increased (Fig.1a).

Although relationship between pH values of bark samples taken from the summit of the trees and tree length was weak, the pH values increased in a similar way as the length increased (Fig.1b). Bark pH values of various tree species varied between 3.5 and 8.0 (Harkin and Rowe, 1971). While pH values of Black pine barks ranged between 3.224 -

Table 1 : Stand tree parameters and physiographical/topographical properties.

Sample area	Tree age	Height (m)	DBH	Altitude	Slope (%)	Aspect	Parent rock	Site class	Stand structure	Sub-district directorate
1	185	13.3	23.7	714	78	NE	Civana Tuff	-	Two storey	Candere
2	26	8.1	11.8	821	24	NW	Civana Tuff	IV	Single storey	Yayla
3	210	21.1	36.3	940	38	S-SE	Granite	-	Two storey	Candere
4	127	14.7	29.0	976	9	NW	Pzsm	IV	Single storey	Alaçam
5	98	24.1	33.0	1126	49	SE	Granite	I	Single storey	Alaçam
6	81	21.0	27.9	1241	33	N	Civana Tuff	II	Single storey	Yayla
7	43	10.2	16.7	1118	27	W	Civana Tuff		Two storey	Candere
8	82	16.8	34.4	1600	13	NE	Kdm	III	Single storey	Değirmeneğrek
9	86	16.9	22.8	1409	25	W	Civana Tuff	IV	Single storey	Yayla
10	109	16.2	22.3	1231	30	SE	Pzsm	III	Single storey	Alaçam
11	182	19.9	30.3	1242	34	SW	Pzsm	IV	Single storey	Alaçam
12	78	25.1	27.7	898	36	S-SE	Granite	I	Single storey	Alaçam
13	71	27.0	31.1	898	26	NE	Granite	I	Single storey	Alaçam
14	47	9.1	12.7	1045	41	N	Pzsm	III	Single storey	Candere
15	85	16.8	32.5	1691	26	W-NW	Dasit	IV	Single storey	Ulus
16	67	16.4	30.9	1230	38	SW	Kdm	III	Single storey	Düğüncüler
17	66	13.0	20.4	964	19	N-NW	Kdm	IV	Single storey	Düğüncüler
18	129	15.4	37.7	953	53	S-SW	Dasit	IV	Single storey	Adalı
19	49	9.9	15.3	1418	21	NW	Granite	-	Two storey	Korucuk
20	68	13.8	21.0	1509	24	S	Granite	-	Two storey	Korucuk

Pzsm: Simav metamorphite, Kdm: Dağardı melange

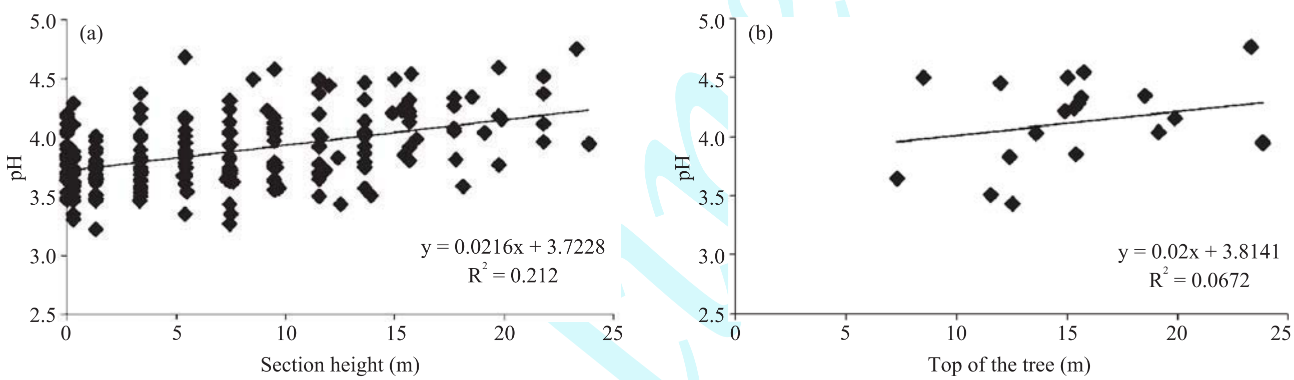


Fig. 1: a) pH values depending on the section height; b) Relationship between the height of the upper end portion and the pH values of the tree

4.759, they had acidic properties. pH values of the litter parts of Black pine forests, where bark is a part of forest floor, was found between 4.4 and 5.4 in istanbul - Bahçeköy (Irmak and Çepel 1974). pH values of the litter parts of Black pine forest that lied up to 1400 m of Mount Ida (Kazdagı) are as follows: between 3.91 to 5.41 at the leaf layer, between 4.37 to 5.88 at fermentation layer, between 5.00 to 6.24 at humus layer (Sevgi, 2003). pH values of leaf and fermentation layer of the litter of Black pine forests that found above 1400 m of Mount Ida (Kazdagı) ranged from 3.52 to 5.00; whereas, pH values of humus layer varied between 3.98 and 6.8 (Sevgi and Tecimen, 2007).

Range of pH values of Black pine bark was 1.535, however, these values varied throughout the tree. Pearson's correlation coefficient between pH of Black pine bark and its section height was 0.458 and significance level was 0.001. R^2 of the generated linear equation was 0.21, its significance level was 0.001 and error margin of estimate was 0.262, consequently, the model is presented as; BR=3.722+ (0.021*SH). This might be due to two reasons: pH of younger barks were higher; as moving downwards the participation rate of young bark drops: Along the tree bark, it may be divided into three parts as branchless portion, the place where dry branches were, and the part where crown was formed. It was thought that these different parts were likely effective in the differentiation of the pH values. The most significant aspect of the Black pine bark pH is that pH underside was low, but high in the upper parts. In Forestry Sciences, breast height diameter is one of the most commonly used variables. The results obtained in our study might provide a reference to researches where pH of DBH bark was the investigated substance.

The logarithmic model established between bark weight and section height were based on the whole values of the sampled trees, besides, linear models were used at the models between bark weight and section height for single trees (Table 2). R^2 of the equations established in single tree were found between 0.64 and 0.93 (Table 2). Estimation error of the equations ranged from 3.88 to 22.21 (Table 2). The 8th sample tree had the highest coefficient value of the section height, while, 11th tree had the lowest one that are 5.123 and 1.963 respectively.

The correlation coefficients between bark weight (g cm^{-2}) and age, barked diameter and sectional height were 0.523, 0.765, 0.001-0700, their significance levels were 0.001. On the other hand, including all the cross sections between bark weight and section age into the process, linear model was applied. R^2 of the obtained equations were 0.27. In the equations established by dividing the data set into two starting from the age of 100, the significance of the relationship changed (Fig. 2a, b). R^2 of the equation between the values that were above the age of 100 was 0.006 (Fig.2b). Also, below the age of 100, R^2 of the relationship went up to 0.488 (Fig. 2a). Similar relationship was found between bark weigh and barked diameter (Fig.3a, b). At the cross-sections

Table 2 : Equations established between bark weight (g cm^{-2}) and section height throughout the trunk (at 0.01 significance level)

Areas	BW=Bark weight (g cm^{-2}) SH=Section height (m)	R^2	Error of estimation	BT= Bark thickness (mm) SH=Section height (m)	R^2	Error of estimation
1	BW = 0.601 - (0.035* SH)	0.64	0.15	BW = 32.639 - (2.509* SH)	0.91	4.25
2	BW = 0.407 - (0.054* SH)	0.87	0.08	BW = 14.524 - (1.895* SH)	0.88	2.58
3	BW = 0.762 - (0.037* SH)	0.61	0.24	BW = 26.041 - (1.247* SH)	0.93	2.58
4	BW = 0.585 - (0.036* SH)	0.91	0.07	BW = 27.797 - (1.971* SH)	0.94	2.87
5	BW = 0.848 - (0.036* SH)	0.68	0.22	BW = 31.048 - (1.469* SH)	0.72	8.08
6	BW = 0.622 - (0.028* SH)	0.84	0.09	BW = 23.736 - (1.303* SH)	0.76	5.74
7	BW = 0.613 - (0.062* SH)	0.81	0.13	BW = 21.876 - (2.465* SH)	0.80	5.52
8	BW = 0.659 - (0.036* SH)	0.91	0.07	BW = 29.244 - (1.806* SH)	0.90	3.90
9	BW = 0.650 - (0.036* SH)	0.73	0.14	BW = 18.890 - (1.163* SH)	0.85	3.14
10	BW = 0.694 - (0.042* SH)	0.67	0.20	BW = 23.051 - (1.606* SH)	0.73	6.13
11	BW = 0.435 - (0.015* SH)	0.69	0.08	BW = 12.828 - (0.618* SH)	0.81	2.24
12	BW = 0.691 - (0.028* SH)	0.70	0.17	BW = 22.533 - (0.941* SH)	0.84	3.65
13	BW = 0.595 - (0.018* SH)	0.81	0.08	BW = 29.403 - (1.225* SH)	0.74	6.92
14	BW = 0.491 - (0.050* SH)	0.88	0.08	BW = 16.786 - (1.938* SH)	0.82	3.92
15	BW = 0.810 - (0.050* SH)	0.83	0.14	BW = 41.173 - (2.783* SH)	0.81	8.87
16	BW = 0.726 - (0.045* SH)	0.80	0.14	BW = 27.610 - (1.875* SH)	0.87	4.70
17	BW = 0.757 - (0.060* SH)	0.83	0.14	BW = 27.823 - (2.249* SH)	0.86	4.79
18	BW = 0.450 - (0.043* SH)	0.89	0.06	BW = 30.334 - (1.934* SH)	0.88	4.16
19	BW = 0.616 - (0.046* SH)	0.88	0.10	BW = 19.729 - (2.055* SH)	0.96	1.75
20	BW = 0.601 - (0.035* SH)	0.64	0.15	BW = 21.868 - (1.782* SH)	0.87	3.86

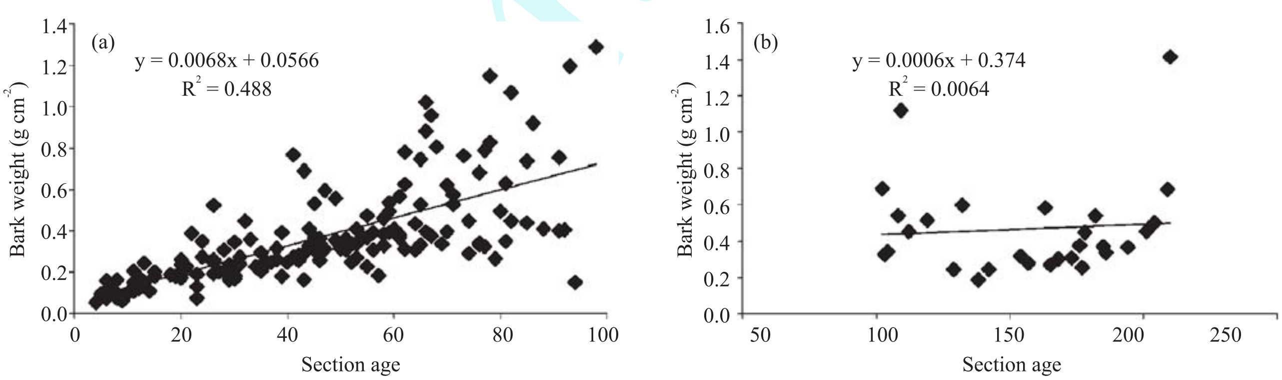
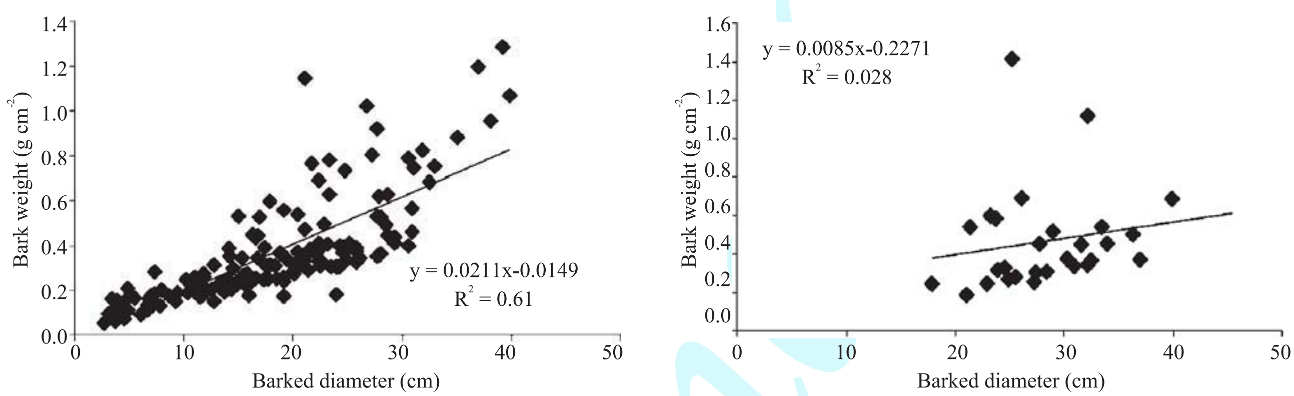


Fig. 2 : Relationships between bark weight (g cm^{-2}) and section age

below the age of 100, R^2 of the relationship between bark weight and barked diameter reached up to 0.61. At the cross-sections above the age of 100, R^2 of the specified relationship was relatively high (0.028). Also, logarithmic equation between bark weight (g cm^{-2}) and section height was BW=0.491- (0.494*ln(SH)) and its R^2 value was 0.64.

R^2 of linear models set up between bark weight (g cm^{-2}) and section height along the trunks of the trees varied between 0.64 and 0.91 (Table 2). Error of estimation of the equations varied between 0.06 and 0.24. Relationship between section height and bark weight was in negative direction (Table 3). The 7th sampling area had the highest coefficient value of section height and its value was 0.062. Also, lowest value was found in the 11th area with 0.015 (Table 2).

With 0.765, barked diameter demonstrated the highest correlation with the sections' bark weight (g cm^{-2}), later with -0.700 section height did; and with 0.523, section age had the least relationship and their significance level was 0.001. With 0.765, barked diameter demonstrated the highest correlation with the sections' bark weight (g cm^{-2}), and later with -0.700, section height; and with 0.523, section age had the least relationship and their significance level was 0.001. Besides, by including all cross sections between bark weight and section age into the process, y = a + bx linear model was applied. R^2 of the obtained equations were 0.27. It is known that cracks on the trunk surface (especially of black pine) get closer to each other after a certain age, and fill in the circumference of the trunk with more barks. Therefore, age of 100 was taken as the limit of the period when more fractured



(a) Cross-sections below the age of 100 (b): Cross-sections above the age of 100

Fig. 3 : Relationships between bark weight (g cm^{-2}) and barked diameter of the section

Table 3 : Linear equations established between bark nitrogen (%) and section height

Sample areas	BNC = Bark nitrogen (%), SH = Section height (m)	R^2	Error of estimation	Significance level
1	BNC = 0.096 + (0.00871* SH)	0.52	0.043	0.028
2	BNC = 0.140 + (0.04052* SH)	0.86	0.054	0.008
3	BNC = 0.122 + (0.00685* SH)	0.77	0.027	0.001
4	BNC = 0.139 + (0.00685* SH)	0.48	0.038	0.038
5	BNC = 0.109 + (0.00719* SH)	0.71	0.036	0.001
6	BNC = 0.133 + (0.00886* SH)	0.59	0.054	0.003
7	BNC = 0.179 + (0.02288* SH)	0.83	0.042	0.005
8	BNC = 0.136 + (0.02084* SH)	0.58	0.100	0.001
9	BNC = 0.151 + (0.01159* SH)	0.83	0.030	0.001
10	BNC = 0.119 + (0.00899* SH)	0.69	0.032	0.005
11	BNC = 0.133 + (0.00772* SH)	0.85	0.024	0.001
12	BNC = 0.133 + (0.00555* SH)	0.56	0.039	0.003
13	BNC = 0.118 + (0.00641* SH)	0.78	0.029	0.001
14	BNC = 0.133 + (0.02377* SH)	0.91	0.030	0.001
15	BNC = 0.176 + (0.00859* SH)	0.45	0.058	0.047
16	BNC = 0.155 + (0.00855* SH)	0.55	0.046	0.014
17	BNC = 0.145 + (0.00745* SH)	0.65	0.022	0.029
18	BNC = 0.139 + (0.00569* SH)	0.64	0.025	0.005
19	BNC = 0.102 + (0.03635* SH)	0.72	0.085	0.015
20	BNC = 0.120 + (0.01808* SH)	0.70	0.061	0.005

structure occurs and when cracks in the trunk get closer to each other; and linear equations were set up again. R^2 of the equation between the values that are above the age of 100 was 0.006 (Fig. 2b). Also, below the age of 100, R^2 of the relationship reached up to 0.488 (Fig. 3a). Similar R^2 results were obtained between bark weight and barked diameter (Fig.3a, b). At the cross-sections below the age of 100, R^2 of the relationship between bark weight and barked diameter increased up to 0.61. At the cross-sections above the age of 100, R^2 of the specified relationship was relatively high, however, the value it reached is 0.028. Also, logarithmic equation between bark weight (g cm^{-2}) and section height was produced to be BW = 0.491 - (0.494*ln(SH)) and its R^2 was 0.64.

Bark thickness and its variation throughout the tree height : Bark thickness was found to be highest (5445 mm) as one-sided (Fig.4). For the all sections of the sample trees, BT= 17.971-(4.199*ln(SH)) logarithmic equation was established. R^2 of the equation was 0.68 and its significance level was 0.01. R^2 of the equations established between single tree section height and bark thickness and, their error of estimation varied between 0.72 and 0.96, 1.75 and 8.87, respectively (Table 2). In other studies it is also indicated that bark thickness decreases depending on the section height (Quilhó *et al.,* 2000; Levia and Wubbena, 2006). It is being expressed that regional differences affect the bark thickness throughout the trunk (Quilhó and Pereira, 2001; McConnon *et al.,* 2004). Relationship between bark thickness and diameter at breast height for six tree species used medicinally in South Africa was significantly explained (Williams *et al.,* 2007). A similar situation was found in the relationship between section height and bark thickness. This may be due to the decrease in diameter depending on the section height. Linear regression models predicting bark thickness at each relative height were derived in Picea abies (Laasasenaho *et al.,* 2005). Therefore, bark thickness throughout a tree would give us the opportunity to make comparisons by enabling the creation of equations for various species.

Change in bark nitrogen (%) values throughout a tree : R^2 of the established equations varied between 0.45 and 0.91, whereas the error of estimation was between 0.022 and 0.100. In the equations; the multiplier (the coefficient) of the section height was 0.00685 in the 3^{rd} and 4^{th} sample trees, and with 0.04052, the highest values were encountered in the sample tree 2.

Linear equation between section height and bark nitrogen % values of the sample trees was BNC% = 0.153 + (SH * 0.008), and significance was determined at 0.001 level, R^2 was 0.30 and error of estimation was 0.0733 (Fig. 5). When nitrogen values of the trees were examined; the highest value was found to be 0.656 % and the lowest 0.085 % (Fig. 5). For Black pine forests, these values come after needle and litter in terms of % values. Analyses of nitrogen on needles of Black pine forests were found between 0.798 and 1.510 in Ankara (Dündar, 1973), between 0.91 and 1.50 in Mount Ida - Edremit (Irmak and Çepel, 1969), between 1.12 and 1.54 in İstanbul - Bahçeköy (Irmak and Çepel, 1959), between 0.97and 1.26 in Florence-Italy (Cenni, et al., 1998). Nitrogen (%) values in needles of Black pine forests above 1400 m of Mounts Ida (Kazdagları) were determined to be between 0.45 and 1.44 (Sevgi and Tecimen, 2010). Trees located in Alaçam mountains, according to the nitrogen analyzes carried out in the needles between 1~4 years of age; these values were determined between 1.412 and 0.609 % (Sevgi *et al.*, 2010). Lowest total nitrogen in deciduous needle was 0.374 and total nitrogen rate was 0.566%. Total average rate of nitrogen was 0.466 % (Sevgi *et al.*, 2010).

Nitrogen % values of the litter parts of Black pine forests was found up to 1400 m of Mount Ida (Kazdagı) vary as follows; between 0.44 and 1.27 at the leaf layer, between 0.32 and 1.56 at the fermentation layer, between 0.19 and 2.21 at the humus layer (Sevgi, 2003). Total nitrogen amounts of litter of Black pine forests that lie above 1400 m of Mounts Ida (Kazdagları) was determined between 10.6 and 119.5 g m^{-2}, and between 5.3 and 478.0 kg ha^{-1} (Sevgi and

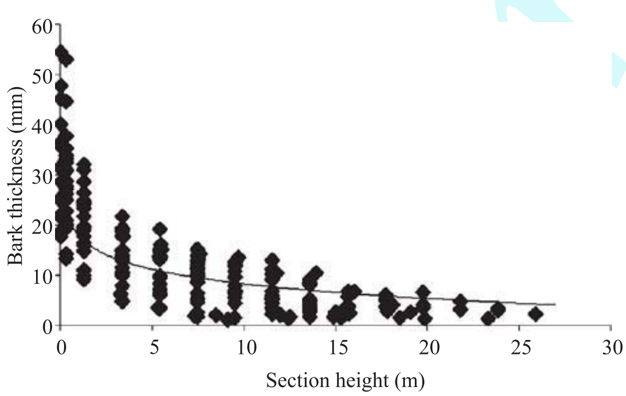


Fig. 4 : Change in bark thickness depending on section height

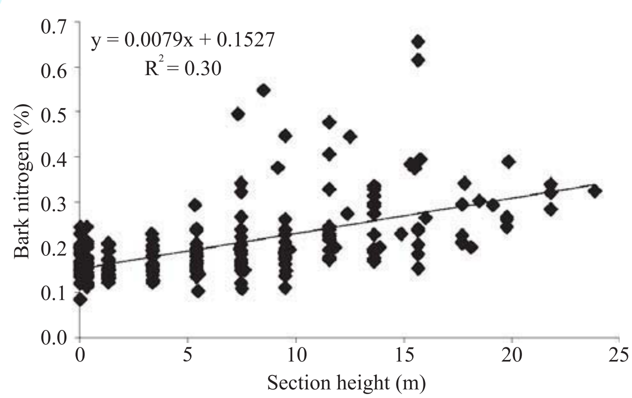


Fig. 5 : Distribution of bark nitrogen (%) values according to section height

Tecimen, 2007).

Linear equation generated by the use of all data between section height and bark nitrogen (%) was determined as follows; BNC% = 0.153 + (SH * 0.008), significance at 0.001 level, R^2 is 0.30, and error of estimation is 0.0733 (Fig.5). For single trees, while R^2 of equations established between Black pine barks nitrogen (%) values and section height varies between 0.45 and 0.91, error of estimation was between 0.022 and 0.100.

Remarkable amount of nitrogen addition to forest floor through being stripped off the barks is thought during the thinning cuttings at forest. The living organisms hosted by tree bark also provides substantial amount of N (organic) by their dead body residues. According to the results obtained in this study; N (%) revealed a raise at young tree barks since N content of young tree barks is higher. For a better explanation of bark properties, the further researches incorporating the essential stand parameters (competition relations, stability, productivity etc.) still remains as a gap to study.

Acknowledgments

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