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Determination of Carbon Concentration of Tree Components for Stone Pine Forests in the Marmara Region

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Research Article

Abstract− In accordance with the Kyoto Protocol, countries prepare their national inventory reports (NIR) every year and present it to United Nations Secretariat of the Framework Convention on Climate Change (UNFCCC). These statements are based on AFOLU Guideline (IPCC Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Use). However, countries are required to produce parameters special to their own tree species in order to make more precise statements. The aim of this study was to determine to calculate both the carbon concentration of various components (needle, wood, bark, and root) of natural stone pine (*Pinus pinea* L.) and the weighted carbon concentration of above ground and total tree biomass. The study was conducted in natural stone pine forests in Marmara Region of Turkey. Samples were collected in 10 sampling plots that were at mature stage (dbh=20.0-51.9 cm) and had different site characteristics. Site characteristics of the sample plots were determined. Then, needle, wood, bark, and root samples were collected from 3 trees representing the top height in each sampling plot. Carbon analysis on plant samples collected from the sampling plots (10 plots × 3 replications × 4 components = 120 samples) was carried out in the laboratory. The obtained data were evaluated by using analysis of variance and Duncan test. Statistically significant differences were found between carbon concentrations of tree components ($P<0.001$). The lowest carbon concentrations were in needle (51.65%) and in roots (51.67%), while the highest carbon concentration was in wood (54.74 %) and in barks (54.93%). The weighted carbon concentration for natural stone pine forests were found to be 54.56% and 54.07% for the above-ground biomass and for the total tree biomass, respectively. The carbon concentrations found in this study can be used to calculate the carbon stocks stored in both trees and different components of trees in natural stone pine forests.

Keywords *− Carbon concentration, climate change, Pinus pinea, Tree components, weighted carbon concentration*

Marmara Bölgesindeki Fıstık Çamı Ormanlarında Ağaç Bileşenlerine Ait Karbon Konsantrasyonlarının Belirlenmesi

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Araştırma Makalesi

Öz− Kyoto protokolü gereği taraf ülkeler her yıl ulusal envanter raporlarını (NIR) hazırlayarak Birleşmiş Milletler İklim Değişikliği Çerçeve Sözleşmesi (UNFCCC) sekretaryasına sunmaktadır. Bildirimler AFOLU (Agriculture, Forestry and Land Use) kılavuzuna göre yapılmaktadır. Ancak daha hassas bildirimlerde bulunmak için ülkelerin kendi ağaç türlerine özgü katsayıları üretmesi gerekmektedir. Bu çalışmanın amacı, ihtiyaç duyulan katsayıların üretilmesi bakımından doğal fıstıkçamı (*Pinus pinea* L.) ormanlarında ağaç bileşenlerinin (ibre, odun, kabuk, kök) karbon oranları ile toprak üstü ve toplam ağaç kütlesine ait ağırlıklı karbon oranlarını belirlemektir. Araştırma, Türkiye'de Marmara Bölgesi'ndeki doğal fıstıkçamı ormanlarında yürütülmüştür. Örneklemeler ağaçlık çağında (dbh=20,0-51,9 cm) bulunan ve yetişme ortamı özellikleri bakımından farklılık gösteren toplam 10 alanda yapılmıştır. Örnekleme alanlarının yetişme ortamı özellikleri belirlenmiştir. Daha sonra her örnekleme alanında meşcere üst boyunda bulunan üç ağaçtan ibre, odun, kabuk ve kök örnekleri alınmıştır. Laboratuvarda örnekleme alanlarından alınan ağaç bileşenlerine ait örneklerde (10 örnek alan × 3 tekerrür × 4 bileşen = 120 örnek) karbon analizi yapılmıştır. Elde edilen veriler varyans analizi ve Duncan testi ile değerlendirilmiştir. Ağaç bileşenlerinin karbon oranları arasında istatistiksel bakımdan önemli farklılıklar belirlenmiştir ($P<0.001$). Karbon yoğunluğu ağaç bileşenleri arasında en düşük ibre (%51,65) ve kökte (%51,67), en yüksek odun (%54,74) ve kabukta (%54,93) bulunmuştur. Doğal fıstıkçamı ormanları için ağırlıklı karbon oranı toprak üstü ağaç kütlesi için %54,56, toplam ağaç kütlesi için ise %54,07 olarak hesaplanmıştır. Elde edilen karbon oranları, fıstıkçamı ormanlarında gerek ağaçlarda gerekse ağaçların farklı bileşenlerinde depolanan karbon stoklarının hesaplanmasında kullanılabilir.

Anahtar Kelimeler *− Ağaç bileşenleri, ağırlıklı karbon konsantrasyonu, iklim değişikliği, karbon konsantrasyonu, Pinus pinea,*

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1. Introduction

Carbon dioxide (CO_2) is one of the greenhouse gases in the atmosphere that causes global warming and climate change. Increasing forestlands is an effective method to reduce CO_2 in the atmosphere by converting CO_2 into organic matter during photosynthesis. Since the forestlands have an important role as a carbon sink, it is essential to make carbon calculations including forest types and tree species in order to monitoring carbon balance in forestlands and performing the necessary calculations to get a better carbon inventory (Lamlom and Savidge, 2003; Malmsheimer et al., 2011). Moreover, tree components of the concerned species and their carbon concentrations should also be calculated for the sake of performing a better carbon calculation of tree species.

Countries are given responsibilities to prepare annual carbon inventories in forestlands as a requirement of Kyoto protocol. A guidelines for carbon inventory (AFOLU-IPCC Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Use) has been prepared to handle carbon calculations and compare them with other countries (IPCC, 2006).

Carbon reservoirs in forest ecosystems have been divided into to three categories. Namely, live below- and above-ground biomass, dead organic matter (dead wood and litter) and organic soil. Regarding the carbon calculations, some experimental coefficients in terms of climate zone, forest type and tree species have been given to be used in this guideline. Those reported experimental coefficients should be verified by studying tree species at local level for more precise calculations, as recommended earlier (IPCC, 2003; IPCC, 2006). A number of studies reported that carbon concentrations in carbon reservoirs vary depending on environmental factors, tree species and tree components (Laiho and Laine, 1997; Lamlom and Savidge, 2003; Bert and Danjon, 2006; Thomas and Malczewski, 2007; Çömez, 2012).

Stone pine, which is native to Portugal, has continued to spread along the Mediterranean coasts up to Anatolia. Because of its edible seeds and being a valuable ornamental tree, the boundaries of its natural distribution areas have been disturbed. Anatolia is one of the significant distribution areas of stone pine with its horticultural cultivation and plantation and big stone pine stands were established for production of pine nut (Yaltırık, 1988). Although it was known as *Pinus sativa*, or *P. maderiensis*, the name *P. pinea* was accepted in 1753 and has been used since then (Shaw, 1914).

Stone pine is primary tree species of “Lauretum” and partly “Castanetum” zones of Mediterranean Flora Region in Turkey (Anşin, 1983). The distribution area of it is under the effect of typical Mediterranean Region climate, and it grows naturally between the altitudes changes from sea level to 600 m above the sea (Yaltırık, 1988).

Above and below ground plant mass and their carbon concentrations as well as carbon stocks of stone pine plantations in Terkos sand dune in Turkey has been reported earlier (Tolunay et al., 2017). According to Serengil’s classification (2018), the study conducted by Tolunay et al. (2017) takes place in Euxine-Colchic, broad-leaved forest ecozone. Present study differs from previous study as it is conducted in natural stone pine forest and takes place in inner Aegean Regio broad-leaved and coniferous forest ecozone.

This study aims to determine the carbon concentrations by above ground biomass and total tree biomass and various components in natural stone pine forests.

2. Material and Method

2.1. Study Area

The research area is between 20 and 150 m altitudes in natural stone pine forests located in the Marmara Region, in the northwest of Turkey (Fig. 1).

Figure 1. A- Turkey in Europe B- Research area in Turkey C- Study area D- Sample plots (Google Earth, 2021).

The data of Armutlu meteorological station, located at the closest distance to the study area, were used to determine the climatic characteristics of the sampling area. The annual precipitation is 632-693 mm, while the annual temperature is 13.7-14.2ºC, and the highest annual temperature is between 18.6 and 19.1ºC (GDM, 2021). According to Erinç method, climate type of the sampling area is semi-humid (Özyuvacı, 1999).

The bedrocks are granitoid and gneiss according to Geological Map of Turkey (GDMRE, 2021), the soil type is Cambisols (IUSS Working Group WRB, 2015). Also, loamy sand and sandy loam soil texture are widespread in the area.

2.2. Sampling Method and Laboratory Analyses

Pure stone pine samples at mature stands were collected from 10 plots that had different aspect, altitude, inclination and slope position. The sampling areas were 20×20=400 m^2. The angle of inclination and the altitude were measured by using the inclinometer and the altimeter, respectively. On the other hand, the aspect was recorded by compass. Slope position was calculated as a percentage in relation to the length of the whole slope. The sampling was completed in May. In each sampling plot, needle, wood, bark, and root samples were collected from three trees in the dominant layer. Needle samples were collected from a height of around 7 meters from the ground with the help of scissors. Needle samples were collected from canopy at the four directions equally by taking into consideration the needles ages and they were compared. Wood and bark samples were collected from the diameter at breast height of the sampled trees with increment borer. In addition, root samples ≤ 5 cm in diameter were extracted from soil by digging the bottom of the sampled trees with pickaxe. The samples were cleaned, and they were carried to the laboratory together with the other samples.

The samples (10 plots×3 replications×4 components = 120 samples) belong to tree components (needle, wood, bark, and root) were dried at a temperature of 65ºC until they reached constant weight and grained for carbon analysis. LECO CNH TruSpec analyser (Leco Corporation, St. Joseph, MI, USA) was used to analyse the carbon concentration of the samples).

2.3. Collecting Plant Samples for Identification

Research field is in the A2 square according to the grid system of Davis. During the fieldworks plant samples were collected as research materials. The plant samples were collected with their flowers, fruits, leaves, stems, and roots which help the identification of the plants. For the identification of plant samples following references were used: Flora of Turkey and East Aegean Islands (Davis, 1965-1985; Davis et al., 1988; Güner et al., 2000). 44 taxa belong to 25 family were identified in the area, and the list of them is given below.

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Aegilops triuncialis subsp. *triuncialis* L., *Aegonychon purpurocaeruleum* (L.) Holub, *Andryala integrifolia* L., *Arbutus andrachne* L., *Arbutus unedo* L., *Arisarum vulgare* O.Targ.Tozz., *Asparagus aphyllus* subsp. *orientalis* (Baker) P.H.Davis, *Asphodeline lutea* (L.) Rchb., *Briza maxima* L., *Campanula lyrata* subsp. *lyrata* Lam., *Clematis flammula* L., *Cistus creticus* L., *Cotinus coggygria* Scop., *Crataegus monogyna* Jacq. var. *monogyna*, *Cynosurus* echinatus L., *Dorycnium pentaphyllum* subsp. *anatolicum* (Boiss.) Gams, *Eremopoa capillaris* R.R.Mill, *Erica manipuliflora* Salisb., *Filago arvensis* L., *Genista acanthoclada* DC., *Geranium robertianum* L., *Hippocrepis emerus* subsp. *emeroides* (Boiss. & Spruner) Lassen, *Juniperus oxycedrus* L. subsp. *oxycedrus*, *Lavandula pedunculata* subsp. *cariensis* (Boiss.) Upson & S.Andrews, *Lonicera etrusca* var. *etrusca* Santi, *Micromeria myrtifolia* Boiss. & Hohen., *Ornithopus compressus* L., *Paliurus spina-christi* P. Mill., *Petrorhagia dubia* (Raf.) G.López & Romo, *Phillyrea latifolia* L., *Pinus pinea* L., *Pistacia terebinthus* subsp. *terebinthus* L., *Poa bulbosa* L., *Prasium majus* L., *Pteridium aquilinum* (L.) Kuhn, *Rumex acetosella* L., *Sarcopoterium spinosum* (L.) Spach, *Silene italica* subsp. *italica* (L.) Pers., *Teucrium polium* L. subsp. *polium*, *Trifolium arvense* var. *arvense* L., *Trifolium campestre* subsp. *campestre* var. *campestre* Schreb., *Trifolium cherleri* L., *Quercus infectoria* subsp. *infectoria* Oliv., *Quercus pubescens* subsp. *pubescens* Willd.

2.4. Evaluation

The single tree biomass for the stances (20.0 < dbh <51.9, here dbh is the diameter at breast height) reported by Tolunay et al. (2017) was used to determine the ratio of the various tree components (needle, wood, bark, and root) mass to the above-ground and total tree biomass. The ratios of needle, wood and bark masses for above-ground biomass were calculated as 0.0625, 0.8656 and 0.0719 respectively, while the ratios of needle, wood, bark and root masses for the total tree biomass were found to be 0.0519, 0.7191, 0.0597 and 0.1693 respectively.

The weighted carbon concentration of above ground and total tree biomass were calculated according to Eq. (1) (Erkan and Güner, 2018) given belove.

$$wcc=\sum(cc_i*cb_i)/100 \quad (2.1)$$

where; wcc is weighted carbon concentration of total biomass (%); ccci is carbon concentration of ith tree component (%); cbi is biomass ratio of ith tree component in total tree biomass (%).

The normality of the data set and also the homogeneity were checked by Shapiro-Wilk and Levene's tests, respectively. All data set exhibited both normally distributed and homogeneous in variance. The differences between the carbon concentration of the wood components were evaluated using variance analysis. Duncan test was used for the datasets that were found to have statistically significant differences following the analysis of variance. Results are accepted statistically significant at α=0.05 level. For the statistical analyses, SPSS statistical software was used (SPSS v.22.0®, 2015).

3. Results and Discussion

3.1. Habitat characteristics of the sample plots

Some site characteristics of sampling areas are presented in Table 1. According to this, the sampling areas are located on 20-132 m altitudes, 2-38% slopes, on sunny and shady aspects, and in the middle and upper slope fields mainly.

Table 1
Some site characteristics of the sample plots

Sample plot	Coordinates (UTM)			Altitude (m)	Inclination (%)	Aspect (°)	Slope position (%)	Location
	GZ	Latitude	Longitude					
1	35T	0658278	4484733	80	33	270 (W)	33 (MS)	Armutlu
2	35T	0658252	4484658	70	35	270 (W)	54 (MS)	Armutlu
3	35T	0659009	4483888	35	2	90 (E)	28 (MS)	Armutlu
4	35T	0660006	4483159	20	18	45 (NE)	60 (MS)	Armutlu
5	35T	0673121	4483390	86	38	270 (W)	27 (MS)	Armutlu
6	35T	0674980	4483214	54	22	180 (S)	5 (US)	Gemlik
7	35T	0674985	4483260	65	22	180 (S)	7 (US)	Gemlik
8	35T	0674998	4483708	132	15	135 (SE)	1 (US)	Gemlik
9	35T	0675144	4483278	56	15	90 (E)	41 (MS)	Gemlik
10	35T	0675144	4483389	78	19	90 (E)	62 (MS)	Gemlik

GZ: grid zone, N: north, NE: northeast, E: east, SE: southeast, S: south, SW: southwest, W: west, NW: northwest, US: upper slope, MS: middle slope

3.2. Carbon concentration of tree components

The descriptive statistics of carbon concentration of tree components are presented in Table 2, while the results of the analysis of variance are given in Fig. 2. Statistically significant differences were found between the carbon concentrations of tree components ($P<0.001$). Needle (%51.65), and roots (%51.67) had the lowest carbon concentration while the highest carbon concentration was found in wood (%54.74) and barks (%54.93) (Table 2, Fig. 2). Similar findings were reported by the studies conducted on different species such as *P. sylvestris* (Çömez, 2012; Erkan and Güner, 2018), *P. nigra* (Güner and Çömez, 2017), and *Cedrus libani* (Karataş et al., 2017), *Abies equitrojani* (Güner, 2019), and *P. pinaster* (Bert and Danjon 2006, Tolunay et al. 2017; Güner et al., 2019). In the study conducted on black pine afforestation areas, it was reported that the carbon concentration of barks was higher than that of the other tree components, which was associated with the high amount of lignin and extractive substances in barks (Güner and Çömez, 2017). The maximum lignin content of wood is around 30% in coniferous species while it is as high as 55% in barks. Moreover, the extractive substance content of barks is known to be 3 times higher than that of wood (Dönmez and Dönmez, 2013). In this study, the absence of a statistically significant difference between the carbon concentrations of wood and bark is thought to be due to the closeness of the wood and bark chemical compositions of the stone pine stands in the researched ecozone. The reason of this situation should be revealed by new researches. However, in the study by Durkaya et al. (2015) conducted on *P. brutia*, *P. sylvestris* and *P. nigra* species, needle had the highest carbon concentration, and it was reported as 52.1; 52.6 and 52.3 respectively. Similarly, in the studies conducted on *Abies bormülleriana* (Durkaya et al. 2013a) and Taurus cedar (Durkaya et al., 2013b) needle had the highest carbon concentration. It is thought that this situation is caused by the differences between the seasons when the samples were collected, stand development stages and habitat characteristics. Likewise, it was stated that carbon concentration differs depending on habitat characteristics (Erkan and Güner 2018, Güner 2019) and stand development stages (Çömez, 2012; Makineci et al., 2015; Güner and Çömez, 2017; Karataş et al., 2017).

Table 2
Some statistics for carbon concentration (%) in tree components (n=30)

Tree Component	Mean	Min.	Max	Std. Dev.
Needle	51.65	51.22	52.10	0.34
Root	51.67	50.66	52.46	0.63
Wood	54.74	51.46	58.25	2.00
Bark	54.93	54.30	55.69	0.49
Weighted mean (Aboveground)	54.56			
Weighted mean (Above- and belowground)	54.07			

Stem wood is the most important carbon sink among the tree components, and its carbon concentration for stone pine was found as 54.74%. This ratio is reported to be 53.0% for the stone pine forests in Portugal (Correia et al., 2010), and it was found as 50.17% for the stone pine plantations in Terkos dune (İstanbul) (Tolunay et al., 2017) (Table 3). Our findings regarding the stem wood were closer to the study conducted in Portugal by Correia et al., (2010). It was thought that 4.5% difference between the two studies conducted in Turkey on the carbon concentration of stem wood may be mostly due to the difference between the establishment of the stands and the ecozones of the research areas. In this study, carbon concentration of needles was found as 51.65%, and it was 45.0% in the study conducted in Portugal (Correia et al., 2010), while it was 49.74% in the study conducted in Turkey (Tolunay et al., 2017). As in stem wood, there are significant differences between studies in terms of needle carbon concentration. It is seasonable to argue that the differences between the habitat characteristics of the research areas play an important role for these results.

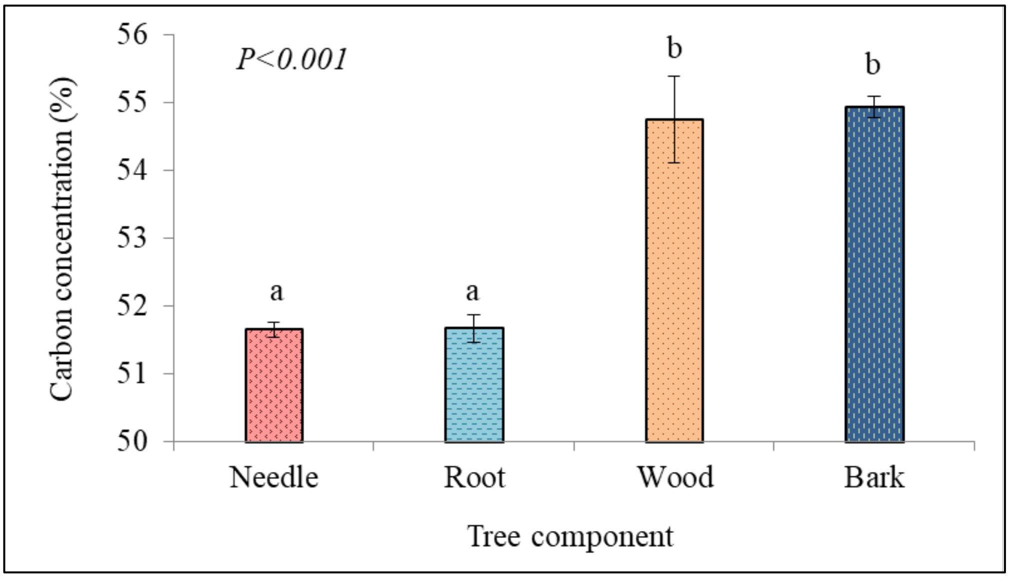

Figure 2. Mean carbon concentration of tree components and ± standard errors. Mean values of each component represented by the same letters were not statistically different from one another at the level of α=0.05

Table 3
Carbon concentration of tree components in pine species (%, Mean)

Species	Tree components					Reference
	Root	Wood	Branch	Needle	Bark	
Pinus pinea	51.67	54.74	-	51.65	54.93	This study
Pinus pinea	50.0	53.0	51.0	45.0	54.0	Correia et al., 2010
Pinus pinea	49.59	50.17	50.77	49.74	53.38	Tolunay et al., 2017

3.3. Weighted carbon concentration

The weighted carbon concentration for stone pine was 54,56%, for above-ground biomass and 54,07% for the total tree biomass (Table 2). In studies conducted on different tree species in Turkey, the weighted carbon concentration of the total tree mass was reported as 51.96% for natural *P. sylvestris* (Tolunay, 2009), 52.46% (Çömez, 2012) and 52.37 % (Erkan and Güner, 2018) as 52.15 % for Kazdağı fir (Güner, 2019); as 53,86 % for *P. nigra* (Güner and Çömez, 2017); as %51.27 for Taurus cedar (Karataş et al., 2017); and as 51.44 % for *P. pinaster* (Güner et al., 2019).The weighted carbon concentration for stone pine plantation was 50.48%, for above-ground biomass and 50.32 % for the total tree biomass (Tolunay et al., 2017). It is thought that 4% difference between the two studies conducted in Turkey on stone pine may be mostly due to the differences between the establishment of forests and habitat characteristics.

According to AFOLU guidelines, if there is no research on the concerned tree species, carbon concentration should be taken as 51% for conifers for carbon sink reporting (IPCC 2006). On the other hand, in many forest-sector carbon balance calculations, carbon concentrations of tree components other than stem wood were not taken into consideration. However, it was shown by our results as well as some of the recent research findings (Çömez, 2012; Güner and Çömez, 2017; Karataş et al., 2017; Tolunay et al., 2017) that there was a significant difference between the carbon concentrations of tree components. Therefore, the coefficients should be re-calculated taking into account of the carbon concentration of weighted tree components for more accurate results.

4. Conclusion

In this study, it was determined that the carbon concentration of tree components in stone pine forests showed significant differences and varied between 51.55% and 54.93%. It was found that weighted carbon concentration was 54.07% for whole tree biomass and 54.56% for above-ground biomass. The results of this study indicate that the biomass ratios of the tree components (needle, wood, bark, and root) should be taken into account while calculating the carbon concentration for a more reliable carbon inventory.

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Author Contributions

Author Bilge Tunçkol: Gathered and analyzed data.

Author Ş. Teoman Güner: He made statistical analyzes of the study and wrote the article.

Conflict of Interest

The authors declared no conflict of interest.

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