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Original Article

Determination of carbon concentration of tree components for Scotch pine forests in Türkmen Mountain (Eskişehir, Kütahya) Region

Türkmen Dağı (Eskişehir, Kütahya) sarıçam ormanlarında ağaç bileşenlerine ait karbon yoğunluklarının belirlenmesi

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ABSTRACT

The purpose of this study was to investigate the relationship between carbon concentration of different tree components and some ecological factors for Scotch pine (*Pinus sylvestris* L. subsp. *hamata* (Steven) Fomin.) in Türkmen Mountain Region. Data were collected from 58 ecologically different sample plots and were evaluated using ANOVA and correlation analysis. Carbon concentration varied significantly within five tree components ($p<0.001$), with the values ranging from 50.94% for root to 54.75% for bark. We also calculated the weighted carbon concentration as 52.37% for Scotch pine forests. Some significant relationships were found between the carbon concentration of tree components and some ecological factors and stand parameters. Site index and elevation negatively correlated with tree component carbon concentration. However, elevation strongly correlated with 1- and 2-year-old needle carbon concentration ($p<0.01$). We also found that slope position positively correlated with 2- and 3-year-old needles but negatively correlated with bark in terms of carbon concentration. The carbon concentrations that we calculated in this study can be used for calculating the carbon content of either whole tree or any tree component in Scotch pine forests.

Keywords: Scotch pine, tree components, carbon concentration

ÖZ

Bu çalışmanın amacı, Türkmen Dağı (Eskişehir, Kütahya) Bölgesi sarıçam (*Pinus sylvestris* L. subsp. *hamata* (Steven) Fomin.) ormanlarında ağaç bileşenlerine ait karbon yoğunlukları ile bazı meşcere ve yetişme ortamı özellikleri arasındaki ilişkileri belirlemektir. Örneklemeler farklı yetişme ortamı özelliklerine sahip 58 alanda yapılmıştır. Elde edilen veriler varyans ve korelasyon analizleri ile değerlendirilmiştir. Altı ağaç bileşeninin karbon yoğunlukları arasında istatistik bakımdan önemli farklılıklar bulunmuştur ($p<0,001$). Karbon yoğunluğu en düşük kökte (%50,94), en yüksek ise kabukta (%54,75) bulunmuştur. Sarıçam ormanları için ağırlıklı karbon oranı %52,37 olarak hesaplanmıştır. Ağaç bileşenlerine ait karbon yoğunlukları ile bazı meşcere ve yetişme ortamı özellikleri arasında önemli ilişkiler tespit edilmiştir. Bonitet endeksi ve yükselti ile ağaç bileşenleri karbon oranları arasında negatif ilişki bulunmuştur. Ancak yükselti ile bir ve iki yaşlı ibre karbon oranları arasındaki ilişki daha güçlü ($p<0,01$) ortaya çıkmıştır. Ayrıca yamaç konumu iki ve üç yaşlı ibre karbon oranı ile pozitif ilişki gösterirken kabuk karbon oranı ile negatif ilişki göstermiştir. Elde edilen karbon oranları, sarıçam ormanlarında gerek ağaçlarda gerekse ağaçların farklı bileşenlerinde depolanan karbon stoğunun hesaplanmasında kullanılabilir.

Anahtar Kelimeler: Sarıçam, ağaç bileşenleri, karbon oranı

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INTRODUCTION

Atmospheric CO_2, which has been continuously rising in the last century, is one of factors that contribute to global warming. There are mainly two strategies for combatting global warming: decreasing the emission and/or increasing the fixation of CO_2. Forests constituting the most important carbon sink in terms of carbon sequestration are good tools available to be used for mitigating carbon content in atmosphere. Therefore, an accurate carbon inventory in forests is essential as a starting point (Asan, 1995; Lamlom and Savidge, 2003; Malmsheimer et al., 2011).

International agreement was reached to decrease the anthropogenic atmospheric gases to avoid climate change (IPCC, 2001). More than 160 countries signed the Kyoto Protocol, which required countries to reduce anthropogenic atmospheric gas emissions during the period from 2008 to 2012 by an average of 5.2% below the levels in 1990 (Colombo et al., 2005). In this context, countries were requested to report the carbon sink change at national level. Moreover, carbon sink change calculations in forestland were expected to be based on AFOLU Guideline (IPCC Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Use) (IPCC, 2006).

This guideline suggested that the annual carbon stock changes should be estimated as the sum of changes in all land-use categories. For land-use category "forest land remaining forest land", changes in ecosystem carbon stocks consist of: 1) living above-ground and below-ground biomass, 2) dead organic matter (i.e., dead wood and litter), and 3) soil organic matter. It is important to estimate carbon content and total biomass of aboveground carbon stocks for the estimation of total carbon stocks in forest ecosystems. The guideline provides some empirical values based on forest type, climate zones and tree species. But it recommends that specific values obtained through research conducted for tree species at local level should be used for a reliable estimation (IPCC, 2003; IPCC, 2006). Because studies show that carbon concentration varies depending on tree species, tree components and other environmental factors (Laiho and Laine, 1997; Lamlom and Savidge, 2003; Bert and Danjon, 2006; Thomas and Malczewski, 2006; Çömez, 2012; Karatepe, 2014; Güner and Makineci, 2017). Therefore, studies on carbon concentration of tree species based on forest types (high forest or coppice, natural or plantation), tree components (root, stem, branch, bark and leaves) and ecological conditions (geographical region, climate type, altitude, slope, and site quality) are essential for accurate carbon reporting.

Scotch pine (*Pinus sylvestris*) is one of the important species in terms of carbon stock change calculations, while it is distributed on an area of 1 518 000 ha (6.8% of total forested area) in Turkey (OGM, 2015) and covers 24% of forested area (about 75 000 000 km^2) in Europe (Janssens et al., 1999). Carbon concentration of Scotch pine in different tree components considering different ecological, geographical region and sites will provide more accurate estimation for reliable national reporting on carbon budget. Therefore, there are various research findings that show carbon concentration changes depending on tree components (Tolunay, 2009; Çömez, 2012; Thomas and Martin, 2012; Güner and Çömez, 2017), geographical regions (Çömez, 2012; Durkaya et al., 2015), formation time of wood (early or late wood) (Lamlom and Savidge, 2003) and even dimension of roots (Akburak et al., 2013). But this study differs from the other research in that we found out the relationships between carbon concentration of tree fractions and some stand parameters and environmental factors.

In this study, we aimed at investigating carbon concentration changes depending on different tree components (root, stem, bark and leaves), some stand parameters (age, Dbh and site index) and physiographical factors (altitude, inclination, slope position and aspect) for Scotch pine in Türkmen Mountain Region. Additionally, we calculated the weighted tree carbon concentration taking account of the biomass ratios of different tree components.

MATERIALS AND METHODS

Study Area

The research was conducted in Türkmen Mountain location situated between 39º16'-39º38 'north latitudes and 30º06'-30º36' east longitudes (Figure 1).

According to the geographical map of Turkey, parent materials in the research area include rhyolite and dacite together with basalt, claystone and limestone (MTA, 2015). The main soil type is grey brown and podsolic grey brown forest soils (Güner, 2006). The climate type of the study area varies from semi-humid to humid in Thornthwaite water balance system. Eskişehir, Kütahya and Afyonkarahisar meteorological stations, which are the closest three data sources, recorded the average annual temperature ranging from 10.6°C to 11.1°C, and annual precipitation from 374 mm to 562 mm.

Scots pine is the dominant species in the study area. Some of the other common plant species in the area include Anatolian black pine (*Pinus nigra* Arnold. subsp. *pallasiana* Lamb. (Holmboe), trembling poplar (*Populus tremula* L.) and oriental beech (*Fagus orientalis* Lipsky.). Main understory species are laurel leaved cistus (*Cistus laurifolius* L.), tinctory oak (*Quercus infectoria* Oliv.), downy oak (*Quercus pubescens* Willd.), Turkish oak (*Quercus cerris* L.), common oak (*Quercus robur* L.), prickly juniper (*Juniperus oxycedrus* L.), wild service (*Sorbus torminalis* (L.) Crantz.), dog rose (*Rosa canina* L.), and hawthorn (*Crataegus pentagyna* Willd.) (Güner, 2006). Some site properties of the study area are presented in Table 1 (Güner et al., 2012).

Sampling Method and Laboratory Analyses

Data were collected from 58 sample plots identified in the study area at different elevations, inclinations and slop positions. In each plot, one sample tree with a dominant position in the stand was cut for analysis. Diameter at breast height and height of tree were measured in cm for accuracy; one-, two- and three-year-old needles were sampled from top shoots. Age was determined at tree stamp cut in October and root samples were extracted from soil by digging with pickaxe. Wood and bark samples were taken from stem at the breast height of the sample tree.

All samples (58 plots×6 components=348 samples) were dried at 65±2°C until constant weight and ground for carbon analysis. Carbon concentration of the samples were analysed using LECO CN TruSpec 2000 elementary analysis device (Leco, 2000).

Site index (SI_{100}) of the sample plots was determined using the site index table prepared by Alemdağ (1967) for natural Scotch pine stands. Slope position (SP) was calculated as percentage in relation to the length of the whole slope. Aspect was recorded

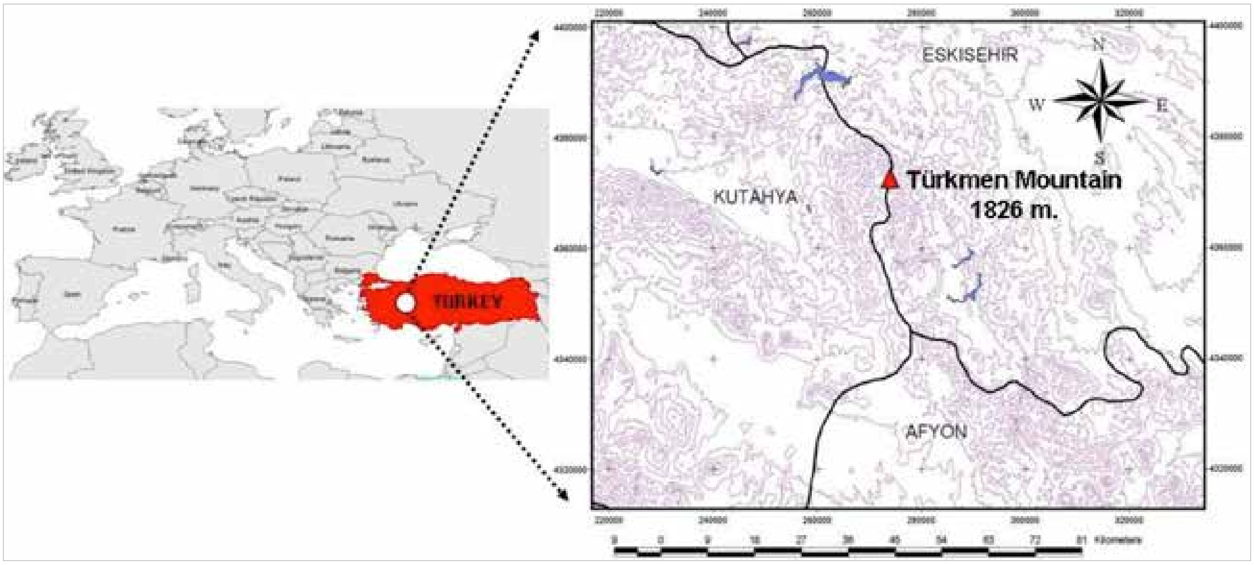

Figure 1. Location of the study area

Table 1. Some site and stand characteristics of sample plots (Güner et al., 2012)

	Mean	Minimum	Maximum
Stand properties			
Stand volume (m3 ha-1)	411.3	218.7	683.2
Stand density (tree ha-1)	1035	500	2000
Stand age (Year)	87	67	108
Diameter at breast height (cm)	23.2	16.8	31.1
Height (m)	17.9	10.3	26.8
Physiographic factors			
Elevation (m)	1492	1222	1708
Inclination (%)	20	3	40
Slope position (%)	51	13	83
Radiation index (dimensionless)	0.516	0.004	0.983
Climatic properties			
Mean annual temperature (°C)	7.8	6.3	8.9
Annual rainfall (mm)	727	609	854
Actual evapotranspiration (mm)	412	399	425
Water deficit (mm)	157	119	183
Water surplus (mm)	286	206	394
Rainfall of the most drought month (mm)	17	13	22
Rainfall from June to September (mm)	145	119	167

as azimuth (*Q*) measured from true north, and converted to a radiation index using the following Formula: 1

$$RI = \left[1 - cos((\pi / 180)(Q - 30))\right] / 2 \quad (1)$$

Where; *RI* is radiation index (dimentionless); *Q* is azimuth (degree).

This assigns a value of zero to a land that orients in north-northeast direction (typically the coolest and wettest orientation) and a value of 1 to the hotter, drier south-southwest facing slopes (Moisen and Frescino, 2002; Aertsen et al., 2010).

The weighted carbon concentration of an individual tree was calculated based on component biomass ratios using Formula 2.

$$wcc = \sum (ccc_i * cb_i)/100 \quad (2)$$

where; wcc is weighted carbon concentration of total biomass (%); ccc_i is carbon concentration of i^{th} tree component (%); cb_i is biomass ratio of i^{th} tree component in total tree biomass (%).

To calculate the weighted carbon concentration, we used the biomass distribution ratios to the tree components prepared by Çömez (2012) for Scotch pine. These ratios were 0.735, 0.046, 0.048, and 0.171 as average of all stand types for stem including branches, bark, needles and cones including root, respectively. We used an average C ratio of one- two- and three-year-old needles to calculate the weighted C ratio of a needle. Therefore, the biomass ratio of a needle was calculated as one value without considering the needle age.

Statistical Analysis

The differences in carbon concentration between the tree components were analysed using ANOVA. Duncan test was applied to get homogeneous groups for the datasets that revealed statistically significant differences (at $p<0.05$ level) after ANOVA. The relationship between the carbon concentration of tree components and some of the tree sizes and physiological factors were tested using correlation analysis. All statistical analyses were performed with Statistical Package for the Social Sciences statistical software (SPSS version 22.0®, 2015).

RESULTS AND DISCUSSION

Carbon Concentration of Tree Components

The variation in the carbon concentration across six tree components was highly statistically significant (F=187.695; p<0.001) with the value ranging from 50.94% for root to 54.75% for bark (Table 2). The variation across the samples was not so high with an average standard deviation of 1.39%. Higher carbon concentration of bark may be due to its higher lignin and extractive content (Güner and Çömez, 2017).

Table 2. Duncan test results and some statistics for carbon concentration (%) in tree components (n=58)

Tree component	Mean*	Minimum	Maximum	Std. Dev.
Root	50.94[a]	49.09	54.60	1.04
One-year-old needle	51.83[b]	50.83	53.08	0.46
Wood	52.55[c]	51.07	54.82	0.74
Two-year-old needle	52.60[c]	51.29	54.14	0.62
Three-year-old needle	53.33[d]	51.53	55.16	0.67
Bark	54.75[e]	52.81	56.39	0.69
Weighted mean	52.37			

*: Letters shows the significantly different carbon concentration values based on ANOVA (p<0.001)
Std. Dev.: standard deviation

Another clear result that we observed was an increase in carbon concentration in consecutive years depending on the age of needles. The average carbon concentrations of one-, two- and three-year-old needles were found to be 51.83, 52.60 and 53.33%, respectively. These results suggested that the carbon concentration was related to the age of needles. However, Bert and Danjon (2006) did not find a significant difference across the ages of needles for carbon concentration in *Pinus pinaster* in France whereas Tolunay (2009) found a significant difference only in three-year-old leaves of one-, two- and three-year-old for Scotch pine trees in Bolu-Aladağ forests. But, when the age of leaves is not considered, i.e. for mixed leaves, we calculated the carbon concentration for Türkmen Mountain as 52.58%, which was slightly lower than the values calculated as 53.02%, 53.8% and 53.19%, respectively, for the same species by Tolunay (2009) for Aladağ Region, by Laiho and Laine (1997) for Finland and by Çömez (2012) for Sündiken Mountains. However, Janssens et al. (1999) calculated the carbon concentration of needles as 48.2% for Scotch pine in Belgium, which was quite lower than the values reported by the other studies. This wide variation in the same species implies the geographical effect on needle carbon concentration.

We calculated the carbon concentration of stem wood, which is the most important carbon sink among the tree components, as 52.55%. For the same species, Laiho and Laine (1997), Janssens et al. (1999), Tolunay (2009) and Çömez (2012) calculated this concentration as 51.80%, 48.90%, 51.20 and 52.31%, respectively.

Bark was found to have the highest average carbon concentration with 54.75% in tree component while the lowest as 50.94%

Table 3. Correlation (Pearson) matrix for relationship between some tree sizes, ecological conditions and tree component carbon concentrations (n=58)[a]

Tree comp.	Factors	Age	Dbh	SI	Incl	Elev	SP	RI
Coynd	Correlation	-0.209	-0.322*	-0.233	0.027	-0.418**	0.274	-0.029
	Sig.	0.116	0.014	0.078	0.838	0.001	0.060	0.845
Ctwynd	Correlation	-0.051	-0.299*	-0.310	0.030	-0.458**	0.354*	0.003
	Sig.	0.706	0.023	0.018	0.826	0.000	0.014	0.985
Ctynd	Correlation	0.040	-0.282*	-0.325*	0.055	-0.314*	0.292*	0.067
	Sig.	0.768	0.032	0.013	0.681	0.016	0.044	0.652
Cwood	Correlation	-0.140	0.279*	0.270*	0.202	-0.031	0.157	-0.014
	Sig.	0.293	0.034	0.040	0.129	0.816	0.287	0.926
Cbark	Correlation	-0.006	0.145	-0.121	-0.261*	0.094	-0.312*	0.277
	Sig.	0.964	0.277	0.364	0.048	0.483	0.031	0.056
Croot	Correlation	0.180	-0.061	-0.117	-0.035	-0.810	-0.024	-0.005
	Sig.	0.176	0.647	0.381	0.793	0.547	0.869	0.974

**Correlation is significant at 0.01 (2-tailed); * Correlation is significant at 0.01 (2-tailed); [a] Coynd: Carbon concentration of one-year-old needles (%); Ctwynd: Carbon concentration of two-year-old needle (%); Ctynd: Carbon concentration of three-year-old needles (%); Cwood: Carbon concentration of wood (%); Cbark: Carbon concentration of bark (%); Croot: Carbon concentration of root (%); Age: tree age (year); Dbh: Diameter at breast height (cm); SI: Site index(m. at T=100); Incl: Inclination of sample plot (%); Elev: Elevation of sample plot (m); SP: Slope position (%); RI: Radiation index (dimensionless) of average carbon concentration was calculated for root. Laiho and Laine (1997), Tolunay (2009) and Çömez (2012) calculated bark carbon concentration as 53.20%, 53.46% and 53.78%, respectively, which were slightly lower than that we found for Scotch pine. Durkaya et al. (2015) calculated bark carbon concentration relatively low as 51.2 % for *Pinus sylvestris*. For Scotch pine, Janssens et al. (1999) and Çömez (2012) calculated root carbon concentration as 49.4 and 51.27%, respectively.

Weighted Carbon Concentration

We calculated the weighted carbon concentration as 52.37% (Table 2), using formula 1. Çömez (2012) calculated the weighted carbon concentration of Scotch pine in Sündiken Mountain (Eskişehir) Region as 52.47%, which was quite similar to our findings. This maybe because of the similarity between the two regions, which are geographically close to one another. Tolunay (2009) and Alakangas (2005) calculated carbon concentration of Scotch pine as 51.96% and 51.80%, respectively, for north-western part of Turkey (Aladağ-Bolu) and for Finland. Güner and Çömez (2017) calculated the weighted carbon concentration as 53.86% for *Pinus nigra* afforested stands sampled in Turkey. Green et al. (2005) and Bert and Danjon (2006) calculated tree carbon concentration as 52.00% and 53.20% respectively, for *Picea sitchensis* and for *Pinus pinaster*.

Guidelines of AFOLU recommend that carbon concentration value should be taken as 51% for conifers for carbon sink reporting in case there is no research specific for related tree species (IPCC, 2006). On the other hand, carbon concentrations of tree components other than stem wood have been excluded from many forest-sector carbon balance calculations so far even if for specific tree species. However, our results in addition to some of the recent research findings showed that carbon concentration of tree components were significantly different from one another (Çömez, 2012; Güner and Çömez, 2017). Therefore, the coefficient calculated taking account of the carbon concentration of weighted tree components will provide a more accurate calculation.

Relationship between Tree Components and Some Stand and Ecological Conditions

Table 3 shows the correlation matrix of tree carbon concentration for tree components, some tree properties and ecological conditions. As shown in the table, not age but Dbh had a significant negative correlation, with $p<0.05$, with one-, two- and three-year-old needles, but a positive correlation with wood carbon concentration. Similarly, Güner and Çömez (2017) found a significant increase in carbon concentration depending on Dbh in *Pinus nigra* plantations. However, this finding was different from some of the others that were found recently. For example, Bert and Danjon (2006) found an insignificant correlation between needle carbon concentration and tree dimensions like stem height, Dbh and length of the crown for some pine species. Çömez (2012) studied the relationship between carbon concentration of tree components and stand type, which is partly related to Dbh and stand age, and reported an insignificant correlation for Scotch pine. Inclination did not have any correlation with the carbon concentration of tree components except for bark. Site index and elevation were negatively correlated with tree component carbon concentration. However, elevation had a stronger correlation at $p<0.01$ with one- and two-year-old needle carbon concentration. This may be explained by decreasing in air temperature depending on elevation which cause increase in sugar transfer to roots but decrease to leaves. Therefore, Hartt (1965) found for sugarcane that sugar was transferred to roots or leaves depending on their temperature comparing to air temperature. Namely, if root temperature is higher than air temperature, sugar transfer to roots will be increased but decreased to leaves. We found that slope position was positively correlated with two- and three-year-old needles but negatively correlated with bark in carbon concentration. Radiation index did not have any correlation with any carbon concentration of tree components.

Studies on the relationship between carbon concentration of tree components and ecological conditions did not allow us to discuss it in details, while further research is needed in this area.

CONCLUSION

We can conclude that carbon concentration varies significantly within tree components ranging from 50.94% to 54.75% for Scotch pine forests in Türkmen Mountain Region. This difference should be taken into consideration while calculating the total biomass carbon concentration. Therefore, weighted carbon concentration found to be 52.37% in this study based on biomass ratios of tree components will provide more reliable national carbon reporting. Moreover, geographical locations also have an impact on carbon concentrations and need to be considered for a more accurate calculation. Furthermore, more research on the relationship between ecological conditions and tree component carbon concentrations will help to take account of more factors for more accurate carbon calculations.

Ethics Committee Approval: This research was not related to ethics issues.

Peer-review: Externally peer-reviewed.

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