ABOVEGROUND BIOMASS AND CARBON STORAGE RELATIONSHIP OF TURKISH PINES

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ABSTRACT

Data related to carbon storage capacities of forests have become increasingly important in the context of global warming. Following the Kyoto Protocol, countries need to understand the carbon storage abilities of their forests in order to perform true declarations. So, we aimed to design allometric biomass and carbon equations able to predict above-ground biomass and amount of carbon, and to enable the conversion of standing stem volumes to stored carbon values of above-ground tree components for *Pinus brutia* Ten, *P. nigra* Arn. and *P. sylvestris* L. trees. Carbon concentrations of tree components were established using tree samples. The biomass and sequestered carbon were modeled from the standing stem volume of single trees, in order to allow the calculation of the carbon sequestered in stands. The study tested different models in determining biomass as a function of *DBH* or *DBH* and *H*. Appropriate functions were chosen and used in the estimation of biomass. The present study makes it possible to safely attain above-ground biomass and sequestered carbon values without any auxiliary operation by using the standing stem volume, which is the most practical element in management plans.

KEYWORDS: *Pinus brutia* Ten., *Pinus nigra* Arn., *Pinus sylvestris* L., above-ground biomass, stem volume, carbon storage, carbon concentration

1. INTRODUCTION

Forest ecosystems provide multilateral benefits for humans at both local and global levels. Information about the tree biomass is required for many purposes, such as understanding the carbon storage and carbon cycle, determining the forest productivity, and estimating of flammable materials in forest fires [1]. Within the global carbon cycle, forest ecosystems play a dominant role, since they hold atmospheric CO_2 and store it within vegetation and soil [2-5]. Exact and accurate determination of the amount of the carbon stored in forest ecosystems and the carbon stock changes has gained importance from the aspect of global carbon cycle, particularly with regard to minimizing the effects of CO_2 emissions. Determination of carbon stocks in forests is also necessary from the aspects of commitments made under the United Nations Framework Convention on Climate Change (UNFCCC), and the implementation obligations brought by Kyoto Protocol [6]. The UNFCCC holds all the parties responsible for preparing, publishing, and periodically updating their national inventories for emissions of gases having sera effects, and any land-use change and forestry changes [7, 8]. In addition, because carbon is becoming a valued product on the global market, estimating the amount of carbon stored in growing trees and harvested wood is becoming increasingly important [9].

Forest inventory data is accepted to be an important resource due to more accurate C storage information, and better reflection of regional heterogeneity through local measurements [10, 11]. The basic input of the carbon calculation method is the commercial wood volume which is obtained from forest inventories, and then, transformed into biomass carbon by being multiplied with biomass expansion factors [12]. Löwe *et al.* [13] have evaluated the implementation of this method in their study on national land-use change and forestry reports of 15 EU-member countries, and have found some deficiencies in transparency, consistency, and completeness. Good Practice Guidance for LULUCF activities requires carbon stock change calculations, made by using objective, transparent, and appropriate methods as well as uncertainties predicted and minimized in time [14]. For this reason, there is an increasing interest in accurate and complete determinability of forest carbon stocks [6]. Although IPCC upholds the use of “bottom-up approach” requiring the use of forest inventories in determining carbon stock changes, the forest inventories generally focus on wood volume for economic reasons, and do not involve data about biomass [15]. If the carbon calculation is performed based on the forest inventory, both aboveground and belowground carbon values will be calculated using biomass expansion factors (BEF) and stem-wood volume, or the biomass equations will be utilized when there are sufficient data [16-18].

According to Article 25 of Kyoto Protocol, Turkey began using the protocol on 26 August 2009. The accurate determination of forest carbon stocks is required for both the

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Kyoto protocol and REDD + (reducing emissions from deforestation and forest degradation in developing countries; and the role of forest conservation enhancement of forest carbon stocks in developing countries) processes [19].

Although GIS-based forest inventories and analyses are easier [20, 21], allometric equations provide more accurate C storage information, and better reflect regional heterogeneity. Allometric equations that allow the estimation of biomass and carbon from the sizes of trees are widely used tools in determining the biomass and carbon stocks [22-25]. Since the general biomass expansion factors do not exactly comply with local conditions in estimation of biomass and carbon stored in a growing stock, they do not provide sufficiently accurate estimated levels. For this reason, the allometric models assessing the local inventory result provide more accurate and reliable results.

Red Pine, Scotch Pine and Black Pine are the most common natural pine species in Turkey. The area covered by Red Pine forests (total of normal and ruined areas) is 5,854,673 h, that of Black Pine is 4,693,060 h, and that of Scotch Pine is 1,479,648 h. These 3 species cover 45% of the total forest surface of Turkey [26], and for this reason, the aboveground biomass models have been developed for these species [27-29]. But, in these studies, the biomasses have been determined as aboveground biomass, body, branch, needle, crown, and whole-tree ones. No classification has been made in branch woods, and no distinction has been made between the wood and bark. The models are based on diameters at breast height (dbh) and diameters at breast height and total tree height (dbh-h), and it requires the re-processing of data making the process harder if the data are not provided in detail in the inventory. Data which can be obtained easily from forest inventories and management plans are standing stem volumes. For this reason, any newly developed models should allow the estimations of biomass and carbon values based on standing stem volume data, and should include commercial and non-commercial levels. Moreover, the determination of commercial and non-commercial branch weights and bark amounts is very important for biomass investors using these wastes as raw material. For these reasons, a new study that rapidly and accurately determines the biomass and carbon stored, has been designed.

Thus, this study examined the following: 1) The determination of commercially valuable above-ground bio-mass which is removed from the forest during harvest as well as those with no commercial values which are left in the forest. 2) The determination of carbon content of above-ground tree components. 3) The development of appropriate models for the conversion of standing stem volume to biomass, and stored carbon values of above-ground tree components.

2. MATERIALS AND METHODS

2.1 Study area

The study has been prepared to be carried out in regions where biomass studies have already been undertaken on these species using complete renewed sampling. The Red Pine samplings were done within the borders of Adana Regional Directorate of Forestry, the Scotch Pine samplings were done within the borders of Erzurum Regional Directorate of Forestry, and the Black Pine samplings were done within the borders of Zonguldak Regional Directorate of Forestry. It is thought that each of the sampling locations is representative of related species.

Adana Regional Directorate of Forestry is located in the southeast of Turkey (36°33'-39°25' N, 30°40'-36°40' E). The Mediterranean climate with hot and dry summers and warm and rainy winters is dominant within this research area. The annual average temperature is 18.7 °C, the maximum summer temperature is 45.6 °C (in August), and the minimum winter temperature is 8.4 °C (in January). The averaged annual precipitation is 646.8 mm and averaged relative humidity is 66%.

Zonguldak Regional Directorate of Forestry is located in the northwest of Turkey (41°00'-41°48' N, 31°10'-32°50' E). The Black Sea climate is dominant within this research area. This climate type is characterized by rain in almost every season; the summers are not hot, and the winters are warm. Annual average temperature is 12.9 °C, maximum summer temperature is 42.8 °C (in July), and minimum winter temperature is 4.1 °C (in January). The average annual precipitation is 1040 mm, maximum monthly precipitation occurs in August (181 mm), and minimum monthly precipitation is 40 mm, during April. Average relative humidity is 55.6%.

Erzurum Regional Directorate of Forestry is located in the northeast of Turkey (38°55'-42°41' N, 38°16'-44°49' E). The winter season is long and cold within the research area. It is generally snowy and frost frequently occurs. The annual average temperature is 10.2 °C, maximum summer temperature is 24.2 °C (in July), and the minimum winter temperature is –4.2 °C (in January). The average annual precipitation is 579.4 mm. The main precipitation occurs in winter and spring. The ratio of summer precipitation is 9.5%, and averaged relative humidity is 60.2%.

2.2 Experimental data

Single trees from pure stands of red pine, scots pine and black pine in different development phases were analyzed in order to determine above-ground biomass development. Each sample tree was selected randomly from trees with no damage. 39 sample trees for red pine, 36 sample trees for scotch pine, and 40 sample trees for black pine (totally 115 trees) were measured from various diameter and height groups. Some characteristics of the sample trees are shown in Table 1. Each sample tree was cut very close to soil level after cleaning the surrounding area. The whole length of the cut trees and diameter at breast height (to the nearest mm and bidirectional) were measured. The branches of the cut sample trees were then removed from the stem. The branches were divided into the two groupings of thinner than 4 cm (non-commercial) and thicker than 4 cm (with commercial value), and were then weighed. The stem was divided into 2.05 m sections and the diameters of the sec-

TABLE 1 - Some characteristics about sample trees.

Pinus brutia (Ten.)									
Sample no	DBH (cm)	Height (m)	Site class	Exposure	Sample no	DBH (cm)	Height (m)	Site class	Exposure
1	24	11.1	II	W	21	23	10.5	III	W
2	17	8.85	II	W	22	31	16.65	III	NW
3	23	11.8	II	SW	23	50	30.85	III	S
4	8	8.6	II	SW	24	26	17.3	III	NW
5	39	24.6	III	SW	25	36	21.4	III	N
6	17	13.15	III	S	26	11	8.3	III	S
7	15	12.2	II	S	27	9	8	II	S
8	32	18.5	II	S	28	8	7.7	II	S
9	38	24.17	II	S	29	15	11	II	S
10	22	15.15	II	S	30	52	29.25	II	SE
11	18	12.1	III	N	31	19	13.5	II	SE
12	25	15.12	III	N	32	29	19	III	SE
13	30	20	III	N	33	13	6.17	III	SE
14	46	27.7	II	N	34	14	7.2	III	SE
15	28	16.2	II	N	35	42	26.7	I	E
16	18	13.2	II	N	36	34	24.2	I	E
17	16	12.2	II	W	37	19	15.8	I	E
18	23	19.6	II	W	38	21	15.1	I	E
19	35	19.6	II	NW	39	32	19.75	II	NE
20	37	20.3	II	NW					
Pinus silvestris (L.)									
Sample no	DBH (cm)	Height (m)	Site class	Exposure	Sample no	DBH (cm)	Height (m)	Site class	Exposure
1	26	20.45	II	S	19	42	26.15	III	NW
2	38	26.1	II	S	20	34	23.76	III	W
3	52	29.8	II	S	21	44	26.67	III	W
4	25	19.45	II	S	22	32	21.6	III	W
5	22	17.95	II	S	23	25	17.95	III	W
6	40	28.5	II	S	24	28	18.85	III	N
7	16	16.26	II	S	25	34	22.15	III	N
8	14	11.75	II	S	26	56	29.4	III	N
9	18	16.68	II	S	27	44	28.36	III	N
10	20	16.35	II	S	28	35	25.19	III	N
11	17	13.86	III	N	29	42	26.35	III	N
12	24	16	III	N	30	58	30.2	III	N
13	11	8.15	III	N	31	15	11.32	III	N
14	28	19.72	III	N	32	36	26.4	III	SW
15	50	30.2	III	N	33	31	21.58	III	SW
16	37	24.9	III	NW	34	24	17.65	III	SW
17	29	21.66	III	NW	35	10	5.55	III	SW
18	55	30.37	III	NW	36	13	8.38	III	SW
Pinus nigra (Arnold.)									
Sample no	DBH (cm)	Height (m)	Site class	Exposure	Sample no	DBH (cm)	Height (m)	Site class	Exposure
1	36	26.2	II	SW	21	15	11.9	III	NW
2	24	16.6	II	SW	22	16	12.3	III	NW
3	25	18.4	II	SW	23	13	9.1	III	NW
4	22	18.1	II	SW	24	25	19.55	III	NW
5	38	24.3	II	SW	25	28	20.3	III	N
6	30	18.3	II	SW	26	30	20.7	III	N
7	24	18.4	II	SW	27	44	28	III	N
8	28	20.8	II	SW	28	42	29.6	III	N
9	26	18.17	II	SW	29	50	29.8	III	N
10	21	15.15	II	SW	30	52	32.25	III	N
11	19	16	III	NW	31	17	14	III	N
12	18	13.9	III	NW	32	8	6.75	III	N
13	12	13.15	III	NW	33	34	21.67	III	N
14	19	14.25	III	NW	34	56	32	III	N
15	17	12.5	III	NW	35	36	27.45	III	N
16	13	11.8	III	NW	36	45	30.3	III	N
17	15	14.2	III	NW	37	46	29.28	III	N
18	16	12.47	III	NW	38	58	25.8	III	N
19	18	13.75	III	NW	39	55	30.9	III	N
20	17	13.6	III	NW	40	28	21.5	III	N

tions at both ends; the diameter of the root collar and the height of the end piece were measured in order to determine the stem volume using the Smalian's formula. Each section was weighed and 5-cm-thick stem samples were taken. All samples were then labeled and preserved in plastic bags.

Stem, branch and needle samples were brought to the laboratory, needles were separated from the shoots, bark was separated from the wood, and fresh weights were determined. Samples were firstly air dried, and then oven-dried at 65±3 °C until the weight was stabilized, and the final dry weights were determined.

2.2 Modelling the above-ground biomass values

The biomass and carbon contents of tree components, such as the stem, branches, leaves, bark, coarse roots and fine roots are generally estimated using different allometric regression models, based on DBH or DBH and H [30-35]. The present study tested different models in determining biomass and carbon amounts as a function of DBH or DBH and H. Appropriate functions were chosen and used in the estimation of biomass and sequestered carbon.

2.3 Measuring carbon concentrations

Dried samples were firstly weighed, divided into small pieces, and then converted into powder as appropriate for carbon analysis. Samples were dried again in order to prevent the effect of moisture, and carbon content was determined via a CN analyser.

2.4 Checking the compliance of models

During the determination of the most appropriate functions, 6 different compliance measures were utilised. These measures are as follows: coefficient of determination (R^2), F value, standard error of estimate (S_e), mean deviation ($\overline{D}$), absolute mean deviation ($\left|\overline{D}\right|$) and total error (TE (%). Average difference, average absolute difference, standard error, total error and average absolute error values should be small, and the coefficient of determination value should be large in order to obtain a reliable model. However, a volume function providing reliable results according to one or more of these values may give inconsistent results according to other variables. In this situation, a "success range", comprising of all of the measured values should be prepared instead of the compared bio-mass function according to measure values [36]. All of these measures were taken into consideration in the selection of appropriate models in this study.

3. RESULTS

The models using the diameter at breast height ($d_{1.3}$) as an independent variable were tested, and those providing the most appropriate results in accordance with compliance measures were determined. Within the biomass equations, the following units of measurement were used: oven dry weight = kg, diameter at breast height (d) = cm, and tree

TABLE 2 - Models using diameter at breast height ($d_{1.3}$) as an independent variable and compliance measures.

Single-Tree Biomass Equations	R^2	F	S_e	TE(%)	$\overline{D}$	$\left\|\overline{D}\right\|$	f	
Pinus brutia (Ten.)								
$S=-18.5158+(0.3299\ .\ d_{1,30})$	0.94	564	56	-0,0073	-0,017	36,37		1
$\mathit{ln}SB=-3.4553+(2.0537\ .\ \mathit{ln}d_{1.30})$	0.85	214	0,42	6,16	2,10	11,18	1.22	2
$CB=-44.5162+(3.1467\ .\ d_{1.30})$	0,78	88	16	0,0023	0,0011	11,55		3
$CBB=-22.9066+(8.833\ .\ lnd_{1.30})$	0,54	29	2,59	-0,00012	$-8x10^{-6}$	1,80		4
$NB=10.3599+(0.0143\ .\ d^2_{1.30})$	0,41	26,1	11,48	-0,13	-0,028	8,10		5
$NBB=3.4972+(-0.0391\ .\ d_{1.30})+(0.0012\ .\ d^2_{1.30})$	0,04	0,79	1,76	-0,021	0,0007	1,42		6
$N=2.5704+(0.020\ .\ d^2{}_{1.30})$	0,79	136	7,0	0,108	0,019	4,56		7
$TC=12.7791+(0.0917\ .\ d^2{}_{1.30})$	0,88	260	23	-0,0053	-0,0044	15,69		8
$WT=-16.7957+(0.4921\ .\ d^2{}_{1.30})$	0,976	1533	51	0,00007	0,00027	33,79		9
Pinus silvestris (L.)								
$S=-29.3855+(0.4035\ .\ d^2_{1.30})$	0,81	152	178	0,0068	0,029	100,2		10
$SB=-7.1523+(0.9525\ .\ d_{1.30})$	0,32	16	18,8	0,0064	0,0014	11,00		11
$CB=-7.3202+(0.0446\ .\ d^2_{1.30})$	0,89	215	13	-0,052	-0,029	9,70		12
$CBB=-0.6482+(0.0048\ .\ d^2_{1.30})$	0,89	202	1,51	-0,74	-0,04	1,11		13
$NB=9.2742+(0.0079\ .\ d^2_{1.30})$	0,55	42	6,6	0,11	0,021	4,93		14
$NBB=1.6276+(0.013\ .\ d_{1.30})$	0,04	1,5	0,83	0,047	0,0009	0,57		15
$N=-10.6443+(1.0553\ .\ d_{1.30})$	0,68	73	9,9	0,0061	0,001	7,00		16
$TC=5.9773+(0.0739\ .\ d^2_{1.30})$	0,92	391	20,3	-0,053	-0,04	14,46		17
$WT=-16.4154+(0.4909\ .\ d^2_{1.30})$	0,85	191	193	-0,0078	-0,042	102		18
Pinus nigra (Arnold.)								
$lnS=-2.3378+(2.3074\ .\ lnd_{1.30})$	0,96	962	0,22	4,19	12,47	54,03	1.05	19
$SB=-85.4624+(36.7215\ .\ lnd_{1.30})$	0,73	104	10,9	-0,0002	$-7,4x10^{-5}$	7,52		20
$CB=-47.6935+(2.7684\ .\ d_{1.30})$	0,79	89	18,4	-0,00024	-0,00012	12,21		21
$CBB=-0.1762+(0.0082\ .\ d^2_{1.30})$	0,79	88	4,13	0,26	0,028	2,80		22
$NB=13.869+(0.0054\ .\ d^2_{1.30})$	0,39	24	6,33	0,059	0,011	5,04		23
$NBB=3.8933+(0.0008\ .\ d^2_{1.30})$	0,19	9,0	1,5	-0,290	-0,013	1,29		24
$N=-1.0982+(5.3496\ .\ lnd_{1.30})$	0,63	64	20,3	-0,0018	-0,00011	1,57		25
$TC=12.9171+(0.0566\ .\ d^2_{1.30})$	0,87	243	21	-0,054	-0,037	13,05		26
$WT=-2.969+(0.4060\ .\ d^2_{1.30})$	0,93	514	103	-0,011	-0,046	59,93		27

(S: Stem, SB: Stem bark, CB: Commercial branch, CBB: Commercial branch bark, NB: Non-commercial branch, NBB: Non-commercial branch bark, N: Needle, TC: Total crown, WT: Whole tree, f: correction factor)

TABLE 3 - Models that use diameter at breast height (*$d_{1.3}$*) and tree height (*h*) as independent variables and compliance measures.

Single-Tree Biomass Equations	R^2	F	S_e	TE(%)	$\overline{D}$	$\lvert\overline{D}\rvert$	f	
Pinus brutia (Ten.)								
$\ln S=-8.4943+(4.3701 . \ln d_{1.30})+(-0.3099 . \ln^2 d_{1.30})+(2.0122 . \ln h)+(-0.3521 . \ln^2 h)$	0.97	238	0.25	4.96	11.83	35.8	1.07	28
$\ln SB=0.2690+(0.0049 . \ln d_{1.30})+(0.3396 . \ln^2 d_{1.30})+(-0.5355 . \ln h)+(0.0971 . \ln^2 h)$	0.86	53	0.42	11.21	3.84	11.25	1.22	29
$CB=2.2226+(0.8552 . d_{1.30})+(-2.9783 . h)+(0.0129 . d_{1.30}^2)+(0.1177 . h^2)$	0.45	6.94	11.6	-7.8×10^{-7}	-1.6×10^{-7}	7.73	_	30
$CBB=1.4072+(0.1915 . d_{1.30})+(-0.6335 . h)+(0.0038 . d_{1.30}^2)+(0.0211 . h^2)$	0.10	0.99	2.21	-1.6×10^{-5}	-5.6×10^{-7}	1.54	_	31
$NB=-39.2483+(8.2235 . d_{1.30})+(-9.3694 . h)+(-0.1201 . d_{1.30}^2)+(0.3589 . h^2)$	0.85	31	14.34	-9.2×10^{-8}	-4.8×10^{-8}	9.25		32
$NBB=-4.3926+(0.9939 . d_{1.30})+(-0.9077 . h)+(-0.0137 . d_{1.30}^2)+(0.0311 . h^2)$	0.57	7.19	2.67	-7.5×10^{-6}	-5.2×10^{-7}	1.73		33
$N=-17.0628+(1.7024 . d_{1.30})+(-0.1436 . d_{1.30} . h)+(0.0023 . d_{1.30}^2)+(1.6375 . h)+(0.0019. d_{1.30}^2 \cdot h)$	0.81	28	6.96	1.1×10^{-6}	2×10^{-7}	4.42		34
$TC=9.6332+(5.6243 . d_{1.30})+(-8.9170 . h)+(-0.0463 . d_{1.30}^2)+(0.3672 . h^2)$	0.90	76	21.83	2.7×10^{-6}	2.3×10^{-6}	14.65		35
$WT=-33.1492+(-6.8963 . d_{1.30})+(12.9051 . h)+(0.6237 . d_{1.30}^2)+(-0.3926 . h^2)$	0.98	363	52.87	-5.5×10^{-8}	-2×10^{-7}	32.59		36
Pinus silvestris (L.)								
$\ln S=0.5511+(5.18181 . \ln d)+(-0.5968 . \ln^2 d)+(-5.8317 . \ln h)+(1.3079 . \ln^2 h)$	0.96	181	0.26	4.13	17.58	87.76	1.08	37
$\ln SB=-6.1099+(3.0555 . \ln d)+(-0.2676 . \ln^2 d)+(0.835 . \ln h)+(-0.0927 . \ln^2 h)$	0.64	14	0.61	26.70	5.93	13.75	1.54	38
$CB=-107.4606+(0.6872 . d_{1.30})+(8.3881 . h)+(0.0455 . d_{1.30}^2)+(-0.2139 . h^2)$	0.90	50	13.9	2.1×10^{-8}	1.19×10^{-8}	9.34		39
$CBB=-10.9238+(-0.0801 . d_{1.30})+(1.0678 . h)+(0.0065 . d_{1.30}^2)+(-0.0249 . h^2)$	0.89	46.6	1.57	7.1×10^{-6}	4.4×10^{-7}	1.05		40
$NB=10.3865+(-2.8359 . d_{1.30})+(3.7344 . h)+(0.0391 . d_{1.30}^2)+(-0.0551 . h^2)$	0.65	15.1	6.02	-2.7×10^{-6}	-5×10^{-6}	4.09		41
$NBB=3.5829+(-0.2554 . d_{1.30})+(0.0956 . h)+(0.0031 . d_{1.30}^2)+(0.0042 . h^2)$	0.23	2.42	0.78	3×10^{-5}	6.08×10^{-7}	0.55		42
$N=13.2274+(0.4919 . d_{1.30})+(-2.6691 . d_{1.30} . h)+(0.0083 . d_{1.30}^2)+(0.1221 . h^2)$	0.73	21.6	9.48	-2.1×10^{-6}	-4.4×10^{-7}	6.26		43
$TC=7.492+(-0.9246 . d_{1.30})+(0.2247 . h)+(0.0697 . d_{1.30}^2)+(0.057 . h^2)$	0.92	93.8	20.83	3×10^{-8}	2.7×10^{-8}	13.91		44
$WT=379.882+(-13.9958 . d_{1.30})+(-47.4277 . h)+(0.2502 . d_{1.30}^2)+(2.710 . h^2)$	0.89	64	170.8	8.3×10^{-8}	-4.4×10^{-7}	91.99		45
Pinus nigra (Arnold.)								
$\ln S=-5.388+(1.0801 . \ln d_{1.30})+(0.1223 . \ln^2 h)+(3.4241 . \ln d_{1.30} . h)+(-0.4942 . \ln . h^2)$	0.97	265	0.21	1.84	5.48	54.27	1.05	46
$\ln SB=-9.9029+(1.5768 . \ln d_{1.30})+(-0.0835 . \ln^2 d_{1.30})+(6.3125 . \ln h)+(-1.0249 . \ln^2 h)$	0.89	71.7	0.26	3.99	1.32	6.86	1.08	47
$CB=-89.9595+(1.7906 . d_{1.30})+(5.8965 . h)+(0.02185 . d_{1.30}^2)+(-0.1581 . h^2)$	0.81	22.2	18.7	1.1×10^{-6}	5.5×10^{-7}	11.89		48
$CBB=-23.423+(0.7409 . d_{1.30})+(1.318 . h)+(0.0034 . d_{1.30}^2)+(-0.0467 . h^2)$	0.85	30	3.68	6.9×10^{-6}	7.6×10^{-7}	2.47		49
$NB=1.6831+(2.9196 . d_{1.30})+(-0.0434 . d_{1.30} . h)+(-0.0501 . d_{1.30}^2)+(0.0016 . d_{1.30}^2 \cdot h)$	0.50	8.60	5.99	-1.8×10^{-5}	-3.5×10^{-6}	5.22		50
$NBB=5.0466+(0.1465 . d_{1.30})+(-0.0022 . d_{1.30} . h)+(-0.003 . d_{1.30}^2)+(0.0002 . d_{1.30}^2 \cdot h)$	0.29	3.51	1.53	0.00018	8.5×10^{-6}	1.12		51
$N=1.6027+(-0.2745 . d_{1.30})+(0.0029 . d_{1.30}h)+(0.0133 . d_{1.30}^2)+(0.2745 . h)+(-0.0003 . d_{1.30}^2 . h)$	0.69	14.8	1.98	8.9×10^{-5}	5.6×10^{-6}	1.21		52
$TC=9.8839+(-0.4785 . d_{1.30})+(0.0237 . d_{1.30} . h)+(0.0875 . d_{1.30}^2)+(-0.0012d_{1.30}^2 . h)$	0.87	57.5	21.6	-5.1×10^{-6}	-3.5×10^{-6}	13.1		53
$\ln WT=-0.5605+(0.5188 . \ln d_{1.30})+(0.1811 . \ln^2 d_{1.30})+(1.329 . \ln h)+(-0.1603 . \ln^2 h)$	0.98	374	0.15	0.30	1.21	56.85	1,02	54

height (*h*) = m. The models that were found to be appropriate (1,.., 27) are shown in Table 2.

The models that use diameter at breast height (*$d_{1.3}$*) and tree height (*h*) as independent variables were tested, and the models providing the most appropriate results according to compliance measures were determined. The models that were considered to be appropriate (28,..54) are given below (Table 3).

3.1 Single Entry Volume Equations

A volume equation is required in order to model the relationship between standing stem volume, and biomass and carbon storage capacities. For forestry practice in Turkey, standing stem volumes are determined on the basis of diameter at breast height. Therefore, the function of volume was determined using this parameter. For this purpose, various models were checked according to compliance criteria, and the following models were adopted for *P. brutia, P. silvestris* and *P. nigra.*

$V_{p.brutia}=0.2285+(-0.0314d_{1.30})+(0.0013d_{1.30}{}^{2})$ $(R^2=0.98)$
$V_{p.silvestris}=0.0485+(-0.0139d_{1.30})+(0.001d_{1.30}{}^{2})$ $(R^2=0.98)$
$V_{p.nigra}=-0.0652+(-0.005d_{1.30})+(0.001d_{1.30}{}^{2})$ $(R^2=0.98)$

V: Stem volume (m^3)
$d_{1.3}$: Diameter at breast height (cm)

3.2 Carbon concentrations of tree components

Carbon contents of tree components were determined using samples from *P. brutia, P. silvestris* and *P. nigra* sample trees. To produce usable carbon determination samples, dried samples of all tree components from sample trees were divided into small pieces, and then ground into powder to be appropriate for carbon analysis.

Carbon content was determined via a CN analyzer as the amount of C (%). Carbon contents of components are shown in Table 4 as minimum, maximum and mean values.

3.3 The relationship between standing stem volume and biomass

Various models were tested in order to enable the determination of biomass amounts from standing stem volumes, and those yielding the best results with regard to compliance criteria were identified. The models (55,...,81) enabling the determination of biomass amounts from standing stem volumes on single tree compliance criteria for these models (Table 5) are given below.

TABLE 4 - Carbon concentrations of tree components.

Tree components	Pinus brutia			Pinus silvestris			Pinus nigra		
	Min. (%)	Max. (%)	Mean (%)	Min. (%)	Max. (%)	Mean (%)	Min. (%)	Max. (%)	Mean (%)
Stem wood	49.2	54.0	51.5	49,3	54,9	51,8	49,2	52,9	51,7
Stem bark	49.0	53.7	50.8	49,2	53,9	51,2	50,2	53,0	51,9
Commercial branch	49,0	54,2	51,6	48,0	54,2	52,3	49,2	53,1	51,5
Commercial branch bark	49,0	53,9	50,3	47,2	53,8	50,7	49,3	52,6	51,5
Non-commercial branch	49,1	53,9	51,4	49,4	54,5	52,1	48,5	52,9	51,8
Non-commercial branch bark	49,0	53,9	50,2	46,5	53,9	50,3	49,0	52,3	51,4
Needle	49,2	54,9	52,1	49,3	55,4	52,6	50,7	53,3	52,3

TABLE 5 - Biomass models using the standing stem volume (*V*) as an independent variable and compliance measure.

Single-Tree Biomass Equations	R^2	F	S_e	TE(%)	$\overline{D}$	$\lvert\overline{D}\rvert$	
Pinus brutia (Ten.)							
S=57.7818+(383.2403 . V)	0.87	249.0	82.4	$3.8x10^{-9}$	$9.4x10^{-9}$	56.09	55
SB=1.0123+(70.1869 . V)	0.79	142	19.9	$-4.5\ x10^{-9}$	$-1.5\ x10^{-9}$	10.80	56
CB=20.0092+(49.6394 . V)	0.71	60.8	18.76	$-7.18\ x10^{-9}$	-0.19	23.16	57
CBB=4.1292+(4.3392 . V)	0.45	20.4	2.83	$-2.15\ x10^{-9}$	-0.17	3.65	58
NB=13.0006+(18.0850 . V)	0.44	30.6	11.09	$1.3\ x10^{-8}$	$2.9x10^{-9}$	8.00	59
NBB=2.9376+(1.1821 . V)	0.09	3.5	2.14	$-1.3\ x10^{-8}$	$-4.5x10^{-10}$	1.52	60
N=7.2879+(22.9944 . V)	0.72	93.9	8.06	$-1.02\ x10^{-8}$	$-1.85x10^{-9}$	5.40	61
TC=33.3869+(107.7994 . V)	0.83	183	27.03	$1.99x10^{-8}$	$1.6x10^{-8}$	19.71	62
WT=93.0500+(580.0232 . V)	0.93	515	86.82	$2.44x10^{-9}$	$8.9x10^{-9}$	61.74	63
Pinus silvestris (L.)							
S=56.5122+(457.7575 . V)	0.78	121	194	$2.15\ x10^{-9}$	$9.15\ x10^{-9}$	105.98	64
SB=10.6333+(14.3936 . V)	0.25	11.61	19.82	$2.6\ x10^{-8}$	$5.9\ x10^{-9}$	12.40	65
CB=5.9767+(48.2800 . V)	0.84	134	16.55	$4.5x10^{-9}$	$2.55x10^{-9}$	11.61	66
CBB=0.7557+(5.2638 . V)	0.84	140	1.76	$4.8\ x10^{-9}$	$3.03x10^{-10}$	1.39	67
NB=10.9262+(8.9737 . V)	0.53	38	6.75	$7.08\ x10^{-9}$	$1.4x10^{-9}$	4.80	68
NBB=1.7679+(0.3224 . V)	0.09	3.47	0.81	$-3.3\ x10^{-8}$	$-6.79\ x10^{-10}$	0.57	69
N=8.2388+(16.9685 . V)	0.60	51.48	11.1	$6.8\ x10^{-9}$	$1.4x10^{-9}$	7.79	70
TC=21.9504+(83.6033 . V)	0.87	236	25.5	$-7.7\ x10^{-9}$	$-6.9x10^{-9}$	17.18	71
WT=89.0959+(555.7543 . V)	0.80	143	217	$-4.4x10^{-9}$	$-2.4\ x10^{-8}$	121.84	72
Pinus nigra (Arnold.)							
S=24.2349+(347.1064 . V)	0.89	309	107.42	$9.66\ x10^{-10}$	$2.8x10^{-9}$	59.73	73
SB=18.7355+(18.3809 . V)	0.58	52	13.82	$4.5\ x10^{-9}$	$1.5\ x10^{-9}$	10.57	74
CB=7.4362+(36.8629 . V)	0.74	67	20.55	$9.10x10^{-9}$	$4.2\ x10^{-9}$	14.19	75
CBB=1.9020+(8.1201 . V)	0.72	62	4.72	$-8.5\ x10^{-10}$	$-9.06x10^{-11}$	3.06	76
NB=14.4833+(6.0093 . V)	0.43	28	6.12	$-2.16\ x10^{-8}$	$-4.15\ x10^{-9}$	4.94	77
NBB=3.9607+(0.9396 . V)	0.22	11	1.53	$-5.59\ x10^{-9}$	$-2.62x10^{-10}$	1.25	78
N=4.0037+(2.9248 . V)	0.59	55	2.13	$1.68\ x10^{-9}$	$1.06x10^{-10}$	1.73	79
TC=22.4316+(59.2768 . V)	0.84	196	23.06	$3.3\ x10^{-9}$	$2.3x10^{-9}$	15.29	80
WT=65.4021+(424.7642 . V)	0.90	344	124	$9.02\ x10^{-9}$	$3.60\ x10^{-8}$	69.29	81

TABLE 6 - Carbon models using standing stem volume (*V*) as an independent variable and compliance measures.

Single-Tree Biomass Equations	R^2	F	S_e	TE(%)	$\overline{D}$	$\lvert\overline{D}\rvert$	
Pinus brutia (Ten.)							
S=29.9048+(197.8347 . V)	0.87	239	43.4	$-3.3\text{x}10^{-5}$	$-4.2\text{x}10^{-5}$	30.0	82
SB=0.7113+(35.3393 . V)	0.80	152	9.7	-0.00037	$-6.4\text{ x}10^{-5}$	5.41	83
CB=10.3653+(25.6425 . V)	0.70	55.1	10.1	-0.00025	$-6.8\text{x}10^{-5}$	6.66	84
CBB=2.0325+(2.1736 . V)	0.46	20	1.41	-0.0019	$-6.6\text{x}10^{-5}$	0.96	85
NB=6.7163+(9.1833 . V)	0.46	31	5.5	-0.00056	$-6.2\text{x}10^{-5}$	4.04	86
NBB=1.4569+(0.6216 . V)	0.10	4.0	1.05	-0.0055	$-9.6\text{x}10^{-5}$	0.76	87
N=3.7178+(12.2857 . V)	0.72	95	4.26	-0.00038	$-3.7\text{x}10^{-5}$	2.85	88
TC=16.4610+(55.7939 . V)	0.83	174	14.3	$4.4\text{x}10^{-6}$	$1.9\text{x}10^{-6}$	10.31	89
WT=47.0772+(288.9679 . V)	0.92	442	46.7	$-2.2\text{x}10^{-6}$	$-4.1\text{x}10^{-6}$	33.3	90
Pinus silvestris (L.)							
S=27.9402+(242.6708 . V)	0.77	119	104	$-8.6\text{ x}10^{-6}$	$-1.9\text{ x}10^{-5}$	57.27	91
SB=5.4422+(7.5990 . V)	0.39	21	7.61	-0,0007	$-8.2\text{ x}10^{-5}$	6.56	92
CB=3.3046+(25.5085 . V)	0.83	120	8.93	$-9\text{x}10^{-5}$	$-2.8\text{x}10^{-5}$	6.28	93
CBB=0.3294+(2.7329 . V)	0.85	142	0.91	-0.0005	$-2.8\text{x}10^{-5}$	6.28	94
NB=5.6977+(4.8269 . V)	0.53	37.71	3.67	-0.0004	$-4.5\text{x}10^{-5}$	2.64	95
NBB=0.9007+(0.1727 . V)	0.09	3.24	0.42	-0.0066	$-6.91\text{ x}10^{-5}$	0.29	96
N=4.4092+(8.9896 . V)	0.59	48	6.04	-0.00028	$-3.3\text{x}10^{-5}$	4.27	97
TC=10.0332+(44.6838V)	0.86	218	14.2	0.00012	$5.7\text{x}10^{-5}$	10.13	98
WT=43.4156+(294.954 . V)	0.80	140	116	$9.8\text{x}10^{-5}$	0.00027	66.39	99
Pinus nigra (Arnold.)							
S=12.5653+(179.7419 . V)	0.89	323	54.42	$2.38\text{ x}10^{-5}$	$3.6\text{ x}10^{-5}$	30.4	100
SB=9.7183+(9.5302 . V)	0.59	53	7.08	-0.0003	$-5.20\text{ x}10^{-5}$	5.42	101
CB=3.7947+(19.1095 . V)	0.74	67	10.64	$-8.6\text{x}10^{-5}$	$-2.1\text{ x}10^{-5}$	7.6	102
CBB=0.9543+(4.2261 . V)	0.72	63	2.43	0.0011	$6.2\text{x}10^{-}$	1.64	103
NB=7.4666+(3.1735 . V)	0.44	29	3.15	0.00029	2.91	2.53	104
NBB=2.0383+(0.4859 . V)	0.23	11	0.79	0.0001	$3.6\text{x}10^{-6}$	0.65	105
N=2.1005+(1.5238 . V)	0.60	55.9	1.11	-0.0007	$-2.5\text{x}10^{-5}$	0.90	106
TC=9.5187+(30.2980 . V)	0.84	194	11.8	0.00013	$4.5\text{x}10^{-5}$	7.76	107
WT=33.8406+(220.0559 . V)	0.91	362	62.95	$-2.17\text{ x}10^{-5}$	$-4.5\text{ x}10^{-5}$	35.45	108

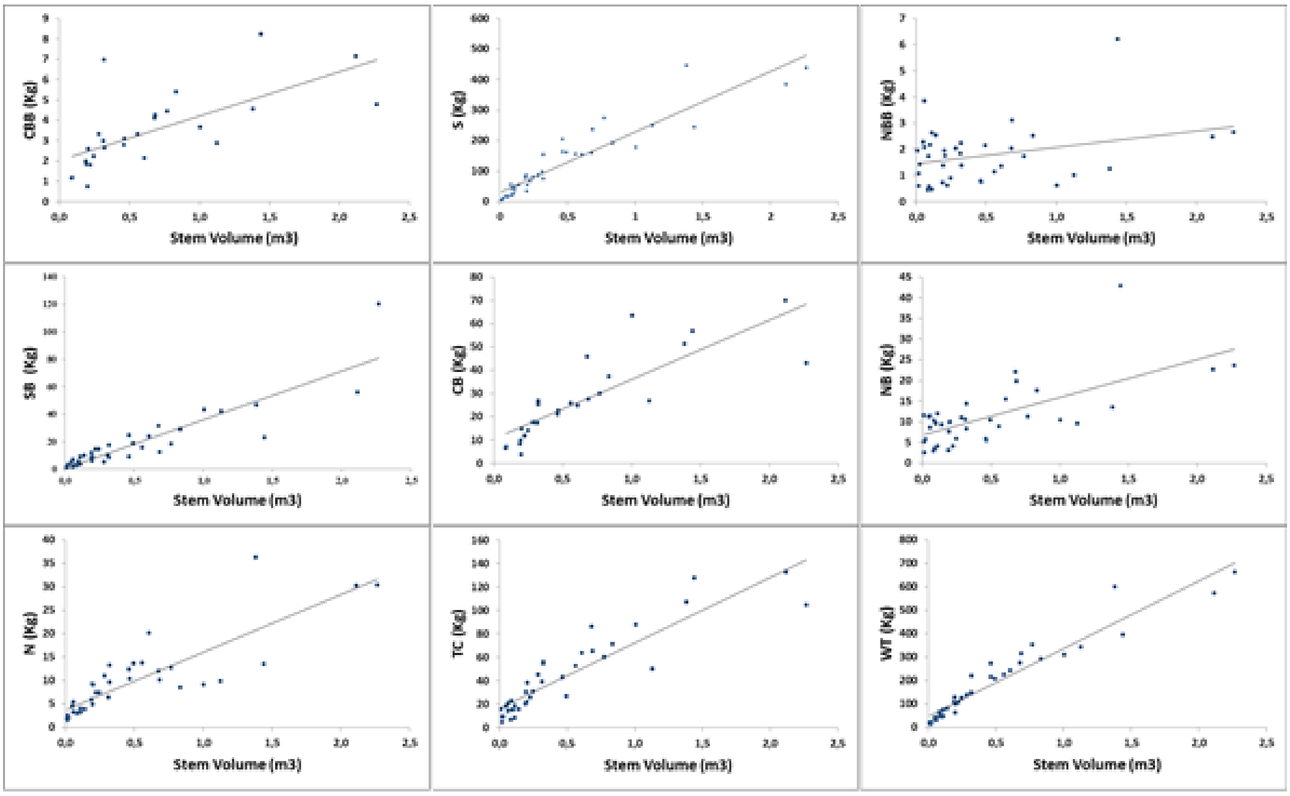

FIGURE 1 - Relations between standing stem volume (m^3) and *P. brutia* tree components.

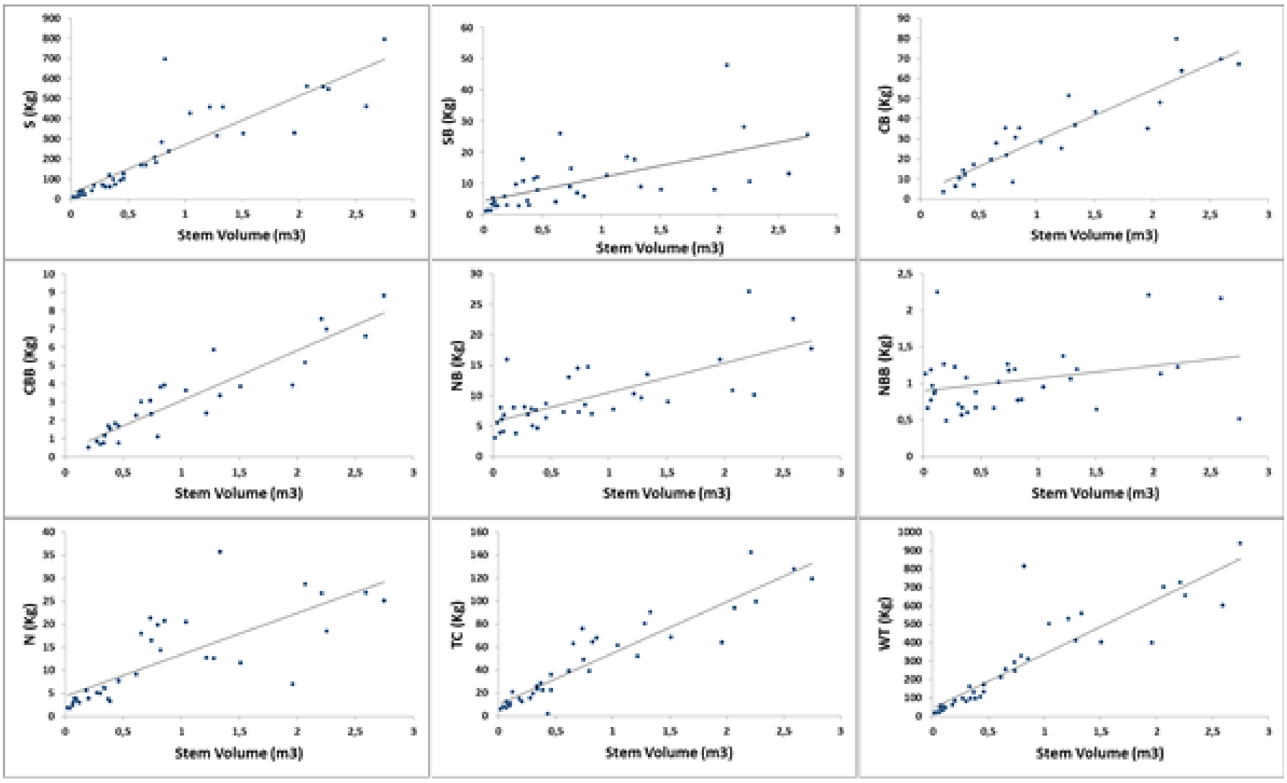

FIGURE 2 - Relations between standing stem volume (m^3) and *P. sylvestris* tree components.

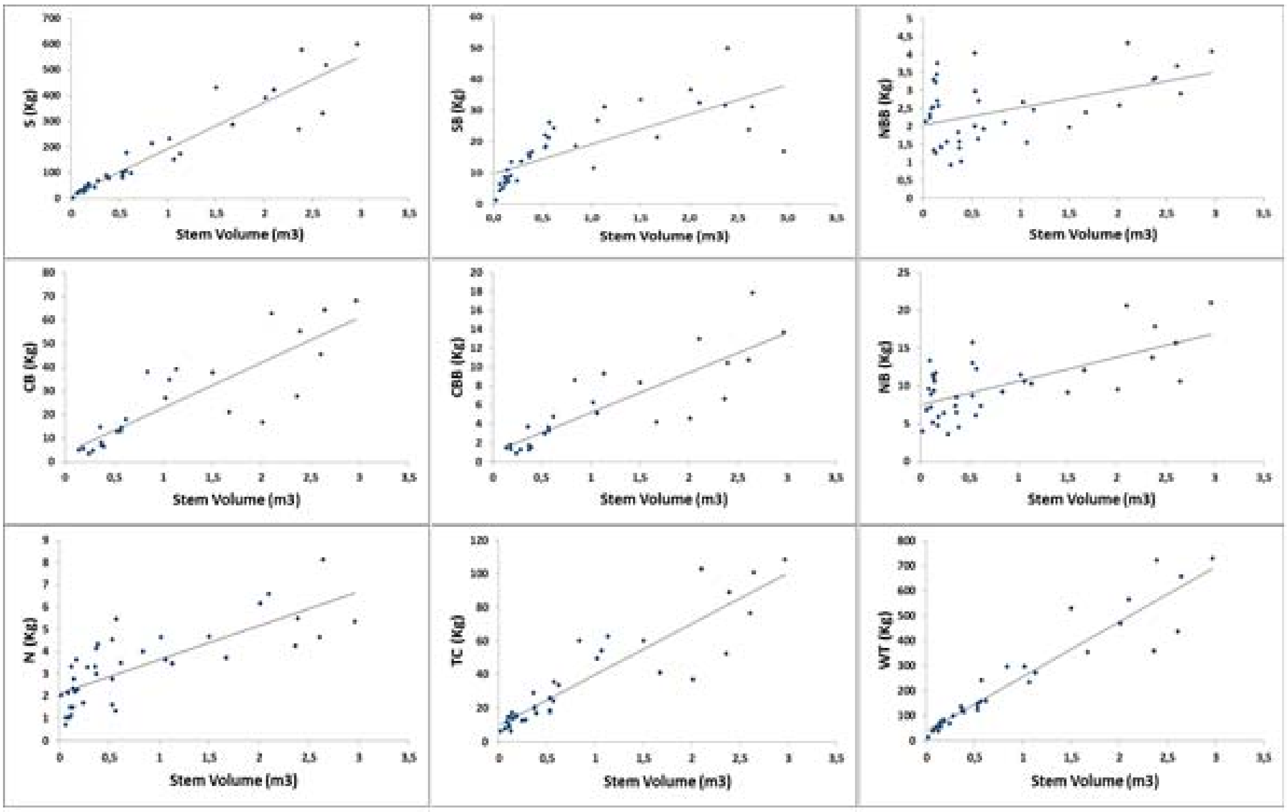

FIGURE 3 - Relations between standing stem volume (m^3) and *P. nigra* tree components.

3.4 The relationship between standing stem volume and sequestered carbon

It is a significant requirement to determine the amount of sequestered carbon from the standing stem volume. Therefore, models that enable the determination of the amount of sequestered carbon and considering the values of standing stem volume were established. These models (82,…,108) and relevant compliance criteria (Table 6) are given below. Relations between standing stem volume and tree components are shown in Figs. 1, 2 and 3.

4. DISCUSSION

The mass-based carbon concentration is widely used in transforming the biomass into carbon storage values. While the average carbon concentration within the body was 49.9 %± 1.3 (mean + SD) in 10 different studies of Zhang *et al.* [37], it varied between 43.7% and 55.6% among the species. This value varied between 46.3% and 55.2% in the study by Lamlom and Savidge [38] covering 41 species. But the general consensus is that the amount of carbon stored can be found by multiplying the total dry weight of the tree by 0.5 [39]. The carbon-concentration of the stem wood in our study was 51.5% for *Pinus brutia*, 51.7% for *P. nigra*, and 51.8% for *P. sylvestris*. While the carbon concentrations were at minimum levels in non-commercial branch barks, they were found to be at maximum levels in needle-leaves. There may be approximately 5% difference between the minimum and maximum values of carbon concentrations of tree components having the same properties. When average carbon concentrations are evaluated in general, it is observed that these values are very close to general consent of 50%.

As seen in Fig. 4, the values obtained from stem volume–whole tree biomass equations for *P. brutia* and *P. sylvestris* were very close to each other. But the *P. nigra* equation was much lower than that of other 2 pine species. In addition, there is a wider range of *P. nigra* values in comparison to the other 2 species.

It is possible to reach the aboveground whole-tree biomass values and stored carbon per hectare values from the presented models by using standing stem volume per hectare as an independent variable. For example; for 2 m^3 standing stem volume, the amounts of stored carbon are 473.95 kg in black pine, 633.32 kg in scotch pine, and 625.13 kg in red pine. While the relationship between whole-tree biomass and stem volume in scotch pine and red pine species were close to each other, it is observed that black pine has lower values. As seen in Fig. 4, the black pine results had a significantly wide range. The result of the study provides a useful output for renewable energy investors and those with an interest in evaluating bi-products. As a general assessment, while 81.28% of all the aboveground biomass is removed from the forest by harvesting, 18.72% is left in the forest.

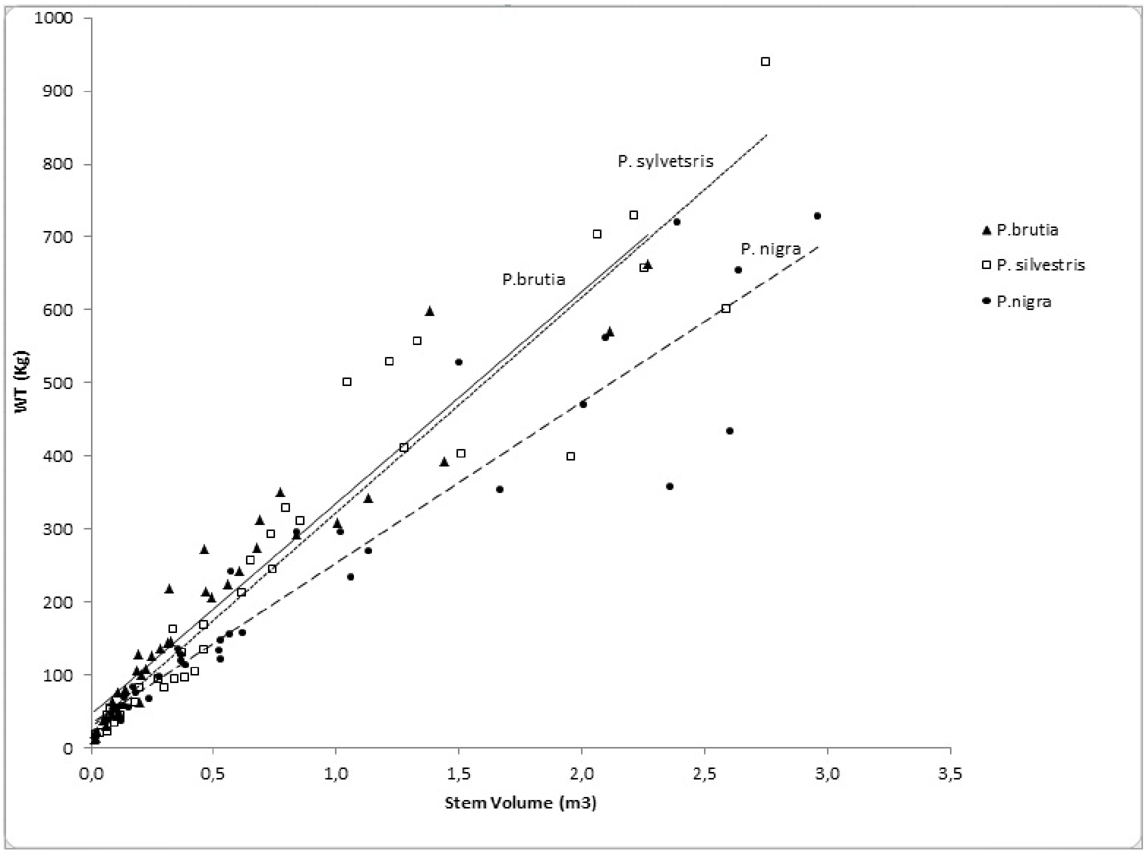

FIGURE 4 - Stem volume-whole tree carbon relations of pine species.

5. CONCLUSIONS

Exact and accurate determination of the carbon amount stored in forest ecosystems and the changes in carbon levels are gaining increasing importance, from both national and international perspectives, in terms of carbon cycle and minimizing the effects of CO_2 emissions [40, 6]. The calculations using BEFs give results that are approximately 17% higher than those made with the models [41]. This situation conflicts with the “exact and accurate determinability” principle expected from the calculations. For this reason, the development and use of regional models for determining carbon storage is of great importance. The data obtained from forest inventories and management plans is the standing stem volume. For this reason, any regional models must allow the estimation of aboveground and belowground biomass and carbon values, in addition to the proportion removed from the forest for commercial use or the amount left in forest due to it having no commercial value.

It is better to execute separate studies for each of the species in order to accurately determine the amounts of carbon stored in forests. As seen, the carbon concentrations show variation depending on various tree species and tree components.

In forestry practice within Turkey, the stand definitions are made based on tree species, tree diameter level, and closure. The tree diameter levels termed “growth stage”, cover a very wide range, and so, it is not possible to utilize the biomass and carbon models based only on tree diameter, or the diameter and height of the tree data in management plans. Further studies are, therefore, needed in this regard. With this study, it is possible to accurately calculate the aboveground biomass and stored carbon values by using standing stem volume values, which are the most useful element in management plans, without any need for any additional process.

Although the aboveground modeling has been made in this study, the belowground carbon storage capacities could not be investigated. The addition of the important information in a future study will add values, and allow an important gap to be closed.

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