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Predicting the above-ground biomass of crimean pine (*Pinus nigra*) stands in Turkey

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Abstract: *In this study, biomass equations are presented for crimean pine (Pinus nigra Arnold) stands within the Zonguldak forest region. A total of 44 sample plots, each of 0.04 ha were chosen in order to define the biomass equations of black pine, the most common needle leaved species in Turkey. A tree which is the most similar to mean tree according to basal area was cut in each sample area as a sample tree. Various models were tested, utilizing the diameter (d) and the height (h) as independent variables and the most suitable models were determined. Using these models, above-ground biomass amounts can easily be acquired for single trees and stands.*

Key words: *Biomass, Crimean pine, Above-ground*
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Introduction

The main aim of carrying out biomass studies in the past was to produce data for renewable energy resources in place of non-renewable energy resources such as fuel oil and natural gas (Alemdag, 1981). Since forests can store solar energy via green mass, they are one of the most obvious sources of sustainable energy. Substituting biomass in place of fossil fuels is strongly recommended as one of the most effective means of reducing carbon dioxide (CO_2) emissions (Schlamadinger and Marland, 1996; Eriksson and Berg, 2007). In terms of estimating the energy that forest biomass can provide from various tree species and determining the whole production amount that can be provided by stands, biomass tables were considered to be more effective than volume tables, and biomass tables were prepared as part of previous studies.

Atmospheric CO_2, having a significant impact among the greenhouse gases that cause global warming, is stored via photosynthesis within forest ecosystems which is one of the six continental ecosystems named as a carbon sink. Forest biomass contains 80% of the continental carbon on the surface and 40% of the underground carbon (Dixon *et al*., 1994; Goodale *et al*., 2002). Recent biomass studies are assessed from the perspective of renewable energy and environmental protection. Biomass studies are widely utilized in studies determining the quantities of atmospheric carbon sequestrated by forest ecosystems.

There have been numerous studies on above-ground biomass carried out in Turkey. These studies were carried out for scots pine (*Pinus silvestris* L.) (Ugurlu *et al*., 1976), calabrian pine (*Pinus brutia* Ten.) (Sun *et al*., 1980), alder (*Alnus* spp) (Saraçoglu, 1988), Beech (*Fagus orientalis* Lipsky.) (Saraçoglu, 1998), oak (*Quercus* spp) (Durkaya, 1998) and chestnut (*Castanea sativa* Mill.) (Ikinci, 2000). While biomass models for scots pine and alder provide biomass values as a function of diameter at breast height (DBH) and tree height (H), the others provide biomass values only as a function of diameter at breast height.

Due to its geographical location and wide variations in climate and topography, Turkey has various areas that are high in plant diversity. Crimean pine forest, one of the most widespread forest types, is well adapted to its growing sites. Crimean pine is a first class forest tree species that can reach 30-35 m in height. It has the greatest coverage after calabrian pine (4.2 million ha) (Anon., 2006a). So crimean pine forests have been studied effectively (Misir *et al,*. 2007; Sevgi and Akkemik, 2007). When the distribution of crimean pine in Anatolia is analyzed, it is found in the inner parts and in southern skirts which are located in the back side of the coast in Northern Anatolia; in northern skirts and in narrow valleys in the Toros Mountains; at higher altitudes facing to the east in the west of Anatolia. Crimean pine has wide pure forest areas at altitudes between 700 and 1400 m except to the east of Black Sea Region. There is no research on crimean pine biomass in spite of its wide geographic distribution. This situation limits research on carbon sink capacity and bio-energy potential of the forests in Turkey and reduces the reliability of the results. In this study it is intended to determine the above-ground biomass values for single trees and stands of the crimean pine.

Materials and Methods

Study area: The study area comprised the forests of Zonguldak Forest region located in the northwest of Turkey (41°00'-41°48' N, 31°10'-32°50' E). Zonguldak forest region comprises the provinces of Zonguldak, Karabük (except Eskipazar district), Bartin and some parts of Bolu Province (a part of Mengen ve Yigilca districts). Zonguldak forest region is bordered by the Black sea in the north and northwest, by Bolu forest region in the south, by Ankara forets region in the southeast, and by Kastamonu forest region in the east. The total area of Zonguldak Regional Forestry Management is 945,000 ha. About 595,000 ha of this include high forests and 21,000 ha coppice forests. The rest consists of open areas.

The Black sea climate is dominant within the research area. In this climate type, it rains in almost every seasons ; the summers are not hot and the winters are warm. Average data from the last 51 yr was obtained from provincial meteorology stations in order to define the climatic characteristics of the research area. According to these data, 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%.

Undisturbed pure crimean pine stands which are in different development phases and have different site features were analyzed in order to determine above-ground biomass development. Within the various parts of Zonguldak, Dirgine and Ulus Forest Directorates where crimean pine stands are most common, a total of 44 sample plots were marked and trees were measured for various diameter and height groups through stratified sampling. As forest stands in Turkey are defined on the basis of tree species, diameter and canopy closure, the principle of determining the biomass development as a function of diameter or diameter and tree height rather than age function was adopted in order to provide a practical means of assessing biomass and energy potential. In study field, crimean pine stands and sample plots are in II and III site (productivity) class areas. Sample plots are divided into numerous groups in terms of slope (10-60%), aspect and altitude (700-1200 m). Sample plots are 20 x 20 m (0.04 ha) and were positioned by taking into consideration the major directions. After numbering all of the trees within the borders, diameter (to the nearest mm and bidirectional), height and crown height (to the nearest 10 cm) were measured for all trees.

Mean tree according to basal area was selected as a sample tree in order to represent each sample plot by considering that a tree which has an average basal area also has an average mass. Only sample trees were selected that had no damage. Each sample tree was cut very close to soil level after cleaning the surrounding area. The whole length of cut trees, crown heights up to the fresh and dry branches, and crown diameter were measured. Then the branches of the cut sample trees were removed from the stem and the needles were also removed from branches. Subsequently the branches and needles were weighed separately and branch and needle samples were taken. The stem was divided into 2.05 m sections. Each section was weighted and 5-cm-thick stem samples were taken from the middle of these sections. All the samples were labeled and preserved in plastic bags.

Stem, branch and needle samples were brought to the laboratory and fresh weights were determined. After samples were air dry, samples were oven dried at 105±3°C until the weight stabilized and the final dry weights were determined. By means of the coefficients of the differences between fresh and oven dried weights of samples, dry weights belongs to total tree and components were determined. By making use of the number of trees in each hectare, above-ground weight value of a single tree was converted into hectare values.

Modeling the above-ground biomass values: The biomass of above-ground tree components such as stem, branches, leaves and bark are generally estimated using different regression models based on DBH (Forrest, 1969; Clark and Saucier, 1990; Naesset, 2004) or DBH and H (Alemdag and Horton, 1981; Champbell *et al.*, 1985; Clark and Saucier, 1990; Naesset, 2004; Miksys *et al.*, 2007). In our study, different models were tested for the determination of biomass as a function of DBH or DBH and H. Appropriate functions were chosen and used for the determination of biomass.

During the determination of the most appropriate functions, six different compliance measures were utilized. These measures are as follows: coefficient of determination (R^2), standard error of estimate (SE), mean deviation ($\overline{D}$), absolute mean deviation ($|\overline{D}|$), total error (TE (%)) and mean absolute error (MAE(%)). Average difference, average absolute difference, standard error, total error and average absolute error values should be small and 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 than one of these values may give inconsistent results according to other variables. In this situation a success range comprising all of the measure values should be prepared in place of comparing biomass functions according to measure values (Reed and Gren, 1984). All of these measures were taken into consider in the selection of appropriate models in this study.

Results and Discussion

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; tree height (h) = m. The models which were found to be appropriate (1-10) as follows:

Single-tree biomass equations:

Stem biomass (SB):
$SB=-103.221+(9.773876d)+(0.103305d^2)$ 1

Branch biomass (BB):
$BB=-35.8478+(15.72827\ln d)$ 2

Needle biomass (NB):
$NB=-0.709426+(0.002182d^2)$ 3

Total crown biomass (CB):
$CB=-43.8643+(19.02144\ln d)$ 4

Whole tree biomass (TB):
$TB=-106.555+(10.61818d)+(0.100728d^2)$ 5

Stand biomass equations:

Stem biomass (SB):
$SB=-41607.1+(6448.48d)+(49.41835d^2)$ 6

Branch biomass (BB):
$BB=-16082.2+(8328.839\ln d)$ 7

Needle biomass (NB):
$NB=954.8952+(1.155269d^2)$ 8

Total crown biomass (CB):
$CB=-19636.9+(10037.1\ln d)$ 9

Whole tree biomass (TB):

$TB = -40920 + (6980.122d) + (46.58692d^2)$ 10

The models which use diameter at breast height ($d_{1.3}$) and tree height as independent variables were tested and the models providing the most appropriate results according to compliance measures were determined. The models which were considered appropriate (11-20) are given below. Compliance measures of all models are given in Table 1.

Single-tree biomass equations:

Stem biomass (SB):

$SB = 184.239 + 11.58726d - 41.292h + 0.045093d^2 + 1.3929h^2$ 11

Branch biomass (BB):

$BB = 24.89055 + 1.337585d - 4.43053h - 0.01408d^2 + 0.137446h^2$ 12

Needle biomass (NB):

$NB = -5.3851 - 0.34479d + 1.161229h + 0.006917d^2 - 0.02796h^2$ 13

Total crown biomass (CB):

$CB = 19.505 + 0.99279d - 3.2693h - 0.0071d^2 + 0.109482h^2$ 14

Whole tree biomass (TB):

$TB = 203.77 + 12.57883d - 44.563h + 0.037942d^2 + 1.502475h^2$ 15

Stand biomass equations:

Stem biomass (SB):

$SB = 170626.7 + 7171.059d - 33201.7h - 5.01253d^2 + 1277.752h^2$ 16

Branch biomass (BB):

$BB = 18786.14 + 813.4997d - 3097.59h - 10.8698d^2 + 107.1968h^2$ 17

Needle biomass (NB):

$NB = -4751.99 - 250.5d + 942.5091h + 4.327317d^2 - 20.767h^2$ 18

Table - 1: Compliance measures of biomass equations, which were considered appropriate

Model no	R^2	F	SE	TE (%)	MAE (%)	$\overline{D}$	$\lvert D \rvert$
1	0.939	320	45.87	0.0000378	12.0	0.0000806	25.568
2	0.604	64.12	4.93	0.00018	25.59	0.0000242	3.42
3	0.54	49.7	1.42	-0.014	48.037	-0.00034	1.09
4	0.660	81	5.29	0.00026	24.12	0.0000421	3.77
5	0.939	317	47	-0.000037	11.79	-0.000085	26.97
6	0.88	155	38570	0.00001928	16.45	0.029601	25258.4
7	0.437	32.64	3665	-0.000003	26.5	-0.00304	2646.1
8	0.299	17.93	1255.2	-0.0000118	54.76	-0.00021	980.87
9	0.45	34.84	4275	0.0003	27.1	0.035	3190
10	0.878	148	40937	-0.000027	16.16	-0.04	26715.7
11	0.959	228	38.8	-0.0010	10.85	-0.00214	23.12
12	0.678	20.55	4.62	-0.0031	24	-0.00042	3.209
13	0.672	20.05	1.24	0.027	42.46	0.0006	0.97
14	0.715	24.5	5.02	0.0089	22.75	0.001	3.56
15	0.959	233.7	39.3	0.000310	10.10	0.0007	23.11
16	0.959	230	23358	0.000217	11.64	0.333	17873
17	0.612	15.38	3158	0.0000674	22.96	0.006	2292
18	0.486	9.22	1115.5	0.000054	47.79	0.00097	856
19	0.592	14.1	3833	0.000212	23.26	0.0250	2739
20	0.959	229	24282	-0.00018	11.13	-0.304	18395

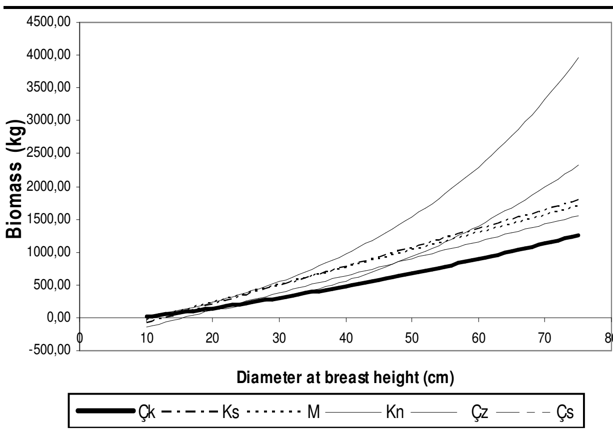

Fig. 1: Biomass changes for single tree according to diameter at breast height for certain species, Ck = Black pine, Ks = Chestnut, M = Oak, Kn = Beech, Cz = Calabrian pine, Cs = Scots pine

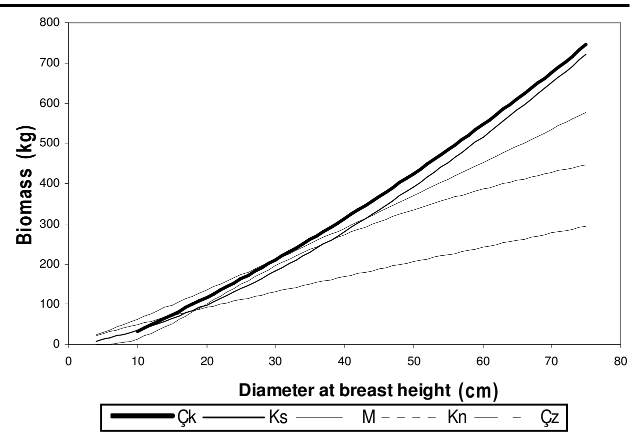

Fig. 2: The change of stand biomass values according to diameter at breast height for the stands in terms of species, Ck = Black pine, Ks = Chestnut, M = Oak, Kn = Beech, Cz = Calabrian pine

Total crown biomass (CB):

$$CB = 14034.15+562.99d-2155.08h-6.5424d^2+86.429h^2 \quad 19$$

Whole tree biomass (TB):

$$TB = 184676.8+7733.29d-35357.9h-11.548d^2+1364.23h^2 \quad 20$$

The findings show that the models using both H and DBH as independent variables demonstrate a stronger correlation than the models using only DBH as an independent variable. This situation is particularly apparent in stand biomass equations. Particularly in needle and branch equations, the correlation of biomass with independent variables is relatively low. This general situation was reported in previous biomass studies (Saracoglu, 1998; Durkaya, 1998; Ikinci, 2000). Stem and whole tree biomass equations exhibited high correlations.

Previously, numerous tables of single tree and stand biomass have been constructed in Turkey. Once the large number of forest tree species is taken into account, the number of studies is inadequate to reliably predict biomass. In these studies oven dry and fresh weight values for single tree or stand are given as stem, crown (branches and leaves) and whole above-ground tree weight. These data are generally derived from models utilizing DBH as independent variable. The alder tables (single tree and stand biomass) prepared by Saracoglu (1988) and scots pine table (single tree biomass) prepared by Ugurlu *et al*. (1976) were generated from models utilizing the DBH and H as independent variables. Besides these, there are some weight studies carried out in order to identify the susceptibility to fire.

The models prepared in the past (providing oven dry for biomass estimates of certain other species according to DBH), and the models identified for crimean pine are compared in Fig. 1. It is observed that beech has the highest single tree weight value according to DBH and crimean pine has the lowest value. It is also observed that crimean pine species has a lower single tree oven dry weight compared with scots pine, calabrian pine, beech, oak and chestnut.

In Fig. 2, the models providing oven dry stand biomass for certain species according to DBH are compared with stand biomass development of crimean pine. The development of stand biomass is almost the same up to 30 cm mean diameter of a stand; after this point crimean pine and alder have higher biomass and calabrian pine has lower biomass. It is striking that crimean pine has the lowest single tree oven dry biomass amount and the highest stand biomass amount. The reason being that the number of crimean pine trees in each hectare is higher than the other species. Average stand heights of the crimean pine are also taller then the heights of calabrian pine.

In needle and branch equations of crimean pine, the correlation of biomass with independent variables is relatively low. It is probable that these differences occurred due to various crown developments arising from non standard stand treatments and due to natural stands sampled.

Biomass equations suitable for practical use in determining the biomass of crimean pine trees and tree components were studied in this study. It is possible to obtain single tree or stand biomass values only by means of diameter at breast height (DBH) or by tree height values (H) and diameter at breast height (DBH) through using these equations. More reliable results may be obtained by using equations predicting biomass amounts according to DBH and H values rather than the values obtained via the equations predicting biomass amounts only according to DBH.

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