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*Full Length Research Paper*

# Predicting the above-ground biomass of calabrian pine (*Pinus brutia* Ten.) stands in Turkey

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**Biomass equations are presented for calabrian pine stands within the Adana-Karaisalı Regional Forestry Management Area. Thirty three sample plots, each of 0.04 ha, were chosen in order to define the biomass equations of calabrian pine, the most common needle leave 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:** Above-ground biomass, calabrian pine, biomass equations.

## INTRODUCTION

Biomass or biological mass comprises the total mass of organic plant matter growing and developing through photosynthesis within a unit area. In the forestry sector, the definition of biomass is understood as the total mass of the trees and shrubs contained in a definite forest area. Biomass in unit area is defined as fresh or oven-dry weight (kg or ton). The moisture content depends on tree species, growing environment, cutting period and climatic conditions etc. Moreover, moisture content differs in lower and upper parts of a vertical cross-section, and horizontal cross section of a tree. Differences in moisture content are also observed between early and summer wood, and between branch wood and heart wood. Biomass can also be accepted as an organic carbon. 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 (Asan, 1999). For these reasons, dry weight values are preferred to fresh weight values, and are the commonly utilized measure of biomass.

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 (Alemdağ, 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, weight tables were considered to be more effective than volume tables, and biomass tables were prepared as part of previous studies.

There have been numerous studies of above-ground biomass carried out in Turkey. These studies were carried out for scots pine (Uğurlu et al., 1976), Calabrian pine (Sun et al., 1980), alder (Saraçoğlu, 1988), beech (Saraçoğlu, 1998), oak (Durkaya, 1998) and chestnut (İkinci, 2000) species. While biomass models for scots pine and alder provide biomass values as a function of

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diameter at breast height (DBH) and tree height (H), the others provide biomass values only as a function of diameter at breast height. In addition, some biomass studies exist that aim to determine fuel loading capacities of some domestic pine species in Turkey (Kucuk et al., 2007; Kucuk and Bilgili, 2008; Kucuk et al., 2008).

Due to its geographical location and wide variations in climate and topography, Turkey has various areas which are high in plant diversity. Calabrian pine forest, the most widespread forest type, is well adapted to its growing environment. It has the greatest coverage (5.4 million ha) (General Directorate of Forestry, 2006). When the distribution of calabrian pine in Anatolia is analyzed, it is found in the Aegean, Mediterranean and Marmara regions as wide areas and along Black Sea cost as little groups (Anşin, 1994). Calabrian pine has wide pure forest areas at altitudes between 100 and 1500 m (Mirov, 1967).

Turkey depends on foreign sources in terms of energy and important part of its budget is spent to fossil fuels. Moreover, in order to comply with the international carbon emission requirements, Turkey sees calabrian pine plantations as a part of the solution. For this reason, ideas about using part of those plantations for energy are growing out. Reliable mass models are needed for the planning stages of energy centrals and for the determination of the capacity of wooden pellets for making production feasibilities. There is an existing research on calabrian pine above-ground biomass. But, this study has been done for calabrian pine stands in low density, so does not represent normal calabrian pine stands. This situation limits research on carbon sink capacity and bioenergy potential of the forests in Turkey and reduces the reliability of the results. In this study it is aimed to generate reliable biomass models to determine the above ground biomass values for calabrian pine species.

## MATERIALS AND METHODS

### Study field

The study area comprised the forests of Adana Forest Administration located in the southeast of Turkey (36°33'-39°25'N, 30°40'-36°40'E). Sample plots were taken between 240 and 1120 m altitudes.

### Climate data

The Mediterranean climate is dominant within the research area. In this climate type, the summers hot and dry, the winters are warm and rainy. Average data from the last 51 years were obtained from provincial meteorology stations in order to define the climatic characteristics of the research area. According to this data, annual average temperature is 18.7°C, maximum summer temperature is 45.6°C (in August), and minimum winter temperature is 8.4°C (in January). The average annual precipitation is 646.8 mm Average relative humidity is 66%.

### Experimental data

Pure calabrian pine stands which are in different development phases and have different site features were analyzed in order to determine above-ground biomass development. A total of 33 sample plots were measured from various diameter and height groups. 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, calabrian pine stands and sample plots are in 1, 2 and 3 site class areas. Sample plots are divided into numerous groups in terms of slope (10-65%), aspect and altitude (240 - 1,120 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 bidirec-tional), height and crown height (to the nearest 10 cm) were mea-sured in 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. The all 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 65±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 belong 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 in the determination of biomass amounts as a function of DBH or DBH and H. Appropriate functions were chosen and used in 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 ($S_e$), mean deviation ($\overline{D}$), absolute mean deviation ($|\overline{D}|$), total error [*TH* (%)], and mean absolute error [*OMH*(%)]. 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 re-sults 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 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 considertion in the selection of appropriate models in this study.

## 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; tree height (h) = m. The models which were found to be appropriate (Tables 1 and 2) (where SB: Stem biomass; BB: Branch biomass; NB: Needle biomass; CB: Total crown biomass and TB: Total above-ground biomass) and their compliance indicators are as follows below (Table 5).

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 (Tables 3 and 4) and their compliance indicators are given below (Table 5).

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 (Saraçoğlu, 1988; Saraçoğlu, 1998; Durkaya, 1998; İkinci, 2000). Stem and total above-ground biomass equations exhibited high correlations.

**Table 1.** Single-tree biomass equations.

| Model no. | Appropriate model |
|---|---|
| 1 | lnSB = -2.52163 + 2.339236lnd (f: 1.091) |
| 2 | lnBB = -4.99881 + 2.558273lnd (f: 1.476) |
| 3 | lnNB = -2.27693 + 1.565827lnd (f: 1.181) |
| 4 | lnCB = -3.16552 + 2.160043lnd (f: 1.143) |
| 5 | lnTB = -1.92352 + 2.243357lnd (f: 1.072 ) |

**Table 2.** Stand biomass equations.

| Model no. | Appropriate model |
|---|---|
| 6 | lnSB = 6.564528 + 1.50280256lnd (f: 1.13 ) |
| 7 | lnBB = 3.525959 + 1.872978lnd (f: 1.19) |
| 8 | lnNB = 6.809221 + 0.729395lnd (f: 1.28) |
| 9 | lnCB = 5.474371 + 1.4437534lnd (f: 1.16) |
| 10 | lnTB = 6.9008376 + 1.4774043lnd (f: 1.11) |

## DISCUSSION

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 Saraçoğlu (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 biomass amounts according to DBH), and the models identified for calabrian pine are compared above (Figure 1). The change of total single tree biomass according to DBH is seen in Figure 1 and mentioned equations are seen in Table 6. It is seen that beech has the highest single tree weight value according to DBH and scots pine has the lowest value. It is observed that calabrian pine species has a moderate single tree oven dry weight compared with scots pine, beech, oak and chestnut. Single tree biomass weights of our model and Sun et al. (1980) model are very close. It is noteworthy that a single tree biomass value of calabrian pine was not lower than other species for the same diameter although it is a fast growing species. Generally, fast growing species are expected to show lower weight characteristics because of having lower volume densities.

In Figure 2, the models providing oven dry stand biomass according to DBH are compared with stand biomass development of calabrian pine. The models giving above ground stand biomass are presented in Table 7. The development of stand biomass is almost the same up to 30 cm mean diameter of a stand; after this point black pine and alder have higher biomass and calabrian pine (Sun et al., 1980) has lower biomass. It is striking that Sun et al. (1980) model has the moderate single tree oven dry biomass amount and the lowest stand biomass amount. The reason for this is that the number of calabrian pine trees in each hectare is lower than the other species. Our model has moderate stand biomass amount. Again in here, lower weight values are not present compared to other stands with same diameter.

In needle and branch equations of calabrian pine, the correlation of biomass with independent variables is relatively low. It is because the crown and needle biomass of trees with the same DBH fluctuates over quite a wide interval (Grigal and Kernik, 1984; Myksis, 1990). These differences occurred due to various crown developments arising from non standard stand treatments, stand age, stocking level and due to natural stands sampled.

**Table 3.** Single-tree biomass equations.

| Model no. | Appropriate model |
|---|---|
| 11 | $SB = 2.943663 - 24.5606d + 30.07571h + 0.630829d^2 - 0.40858h^2$ |
| 12 | $BB = 40.67149 - 7.70616d + 5.30826h + 0.199455d^2 - 0.14033h^2$ |
| 13 | $NB = -10.928 + 1.360196d + 0.002033h - 0.00855d^2 + 0.007008h^2$ |
| 14 | $CB = 29.74345 - 6.34596d + 5.310292h + 0.190901d^2 - 0.13332h^2$ |
| 15 | $TB = 32.68711 - 30.9066d + 35.38601h + 0.821729d^2 - 0.5419h^2$ |

**Table 4.** Stand biomass equations.

| Model no. | Appropriate model |
|---|---|
| 16 | $SB = -98215.7 - 4421.52d + 23233.23h + 110.0105d^2 - 472.32h^2$ |
| 17 | $BB = -7220.86 - 1058.58d + 2756.2h + 37.46634d^2 - 71.727h^2$ |
| 18 | $NB = -10556.4 + 1197.527d + 606.7933h - 16.9448d^2 - 21.5218h^2$ |
| 19 | $CB = -17777.3 + 138.9486d + 3362.994h + 20.52159d^2 - 93.2488h^2$ |
| 20 | $TB = -155993 - 4282.57d + 26596.22h + 130.5321d^2 - 565.568h^2$ |

**Table 5.** Compliance measures of biomass equations which were considered appropriate.

| Model no. | $R^2$ | F | Se | TMH% | OMH% | $\overline{D}$ | $\lvert\overline{D}\rvert$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.95 | 529.78 | 0.27 | 6.13 | 14.66 | 16.37 | 39.15 |
| 2 | 0.82 | 141.5 | 0.58 | 24.12 | 42.41 | 13.78 | 24.23 |
| 3 | 0.80 | 123 | 0.38 | 14.7 | 29.63 | 3.18 | 6.41 |
| 4 | 0.84 | 166.75 | 0.45 | 28.26 | 39.73 | 22.26 | 31.3 |
| 5 | 0.83 | 154 | 0.32 | 11.06 | 26 | 13121.7 | 30844.2 |
| 6 | 0.84 | 162 | 0.39 | -6.5 | 29.58 | -1458.5 | 6636.4 |
| 7 | 0.37 | 18 | 0.46 | 17.26 | 40.77 | 1934.15 | 4568.4 |
| 8 | 0.79 | 117 | 0.36 | 9.85 | 30.34 | 3313.9 | 10206.4 |
| 9 | 0.85 | 170 | 0.30 | 8.81 | 25.07 | 13426.7 | 38174.1 |
| 10 | 0.83 | 154 | 0.32 | 11.06 | 26 | 13121.7 | 30844.2 |
| 11 | 0.968 | 215.2 | 46.63 | 0.000332 | 11.42 | 0.000887 | 30.512 |
| 12 | 0.824 | 32.9 | 30.3 | -0.00194 | 31.25 | -0.0011 | 17.85 |
| 13 | 0.748 | 20.8 | 6.92 | 0.012 | 23.06 | 0.0026 | 4.99 |
| 14 | 0.841 | 37.05 | 33.01 | 0.000584 | 25.207 | 0.00046 | 19.85 |
| 15 | 0.952 | 139.5 | 74.7 | -0.00017 | 13.7 | -0.0006 | 47.38 |
| 16 | 0.837 | 35.9 | 29775.4 | 0.000099 | 19.11 | 0.118 | 22674.69 |
| 17 | 0.759 | 22.07 | 10275.3 | -0.00034 | 30.90 | -0.07 | 6932.38 |
| 18 | 0.370 | 4.12 | 4857.4 | 0.000113 | 29.96 | 0.012 | 3356.773 |
| 19 | 0.679 | 14.8 | 13713.1 | 0.0000000384 | 28.17 | 0.0000129 | 9478.54 |
| 20 | 0.814 | 30.7 | 41515.79 | 0.000209 | 20.76 | 0.318 | 31618.7 |

## Conclusions

Biomass equations suitable for practical use in determining the biomass of calabrian 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 tree height values (H) and 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.

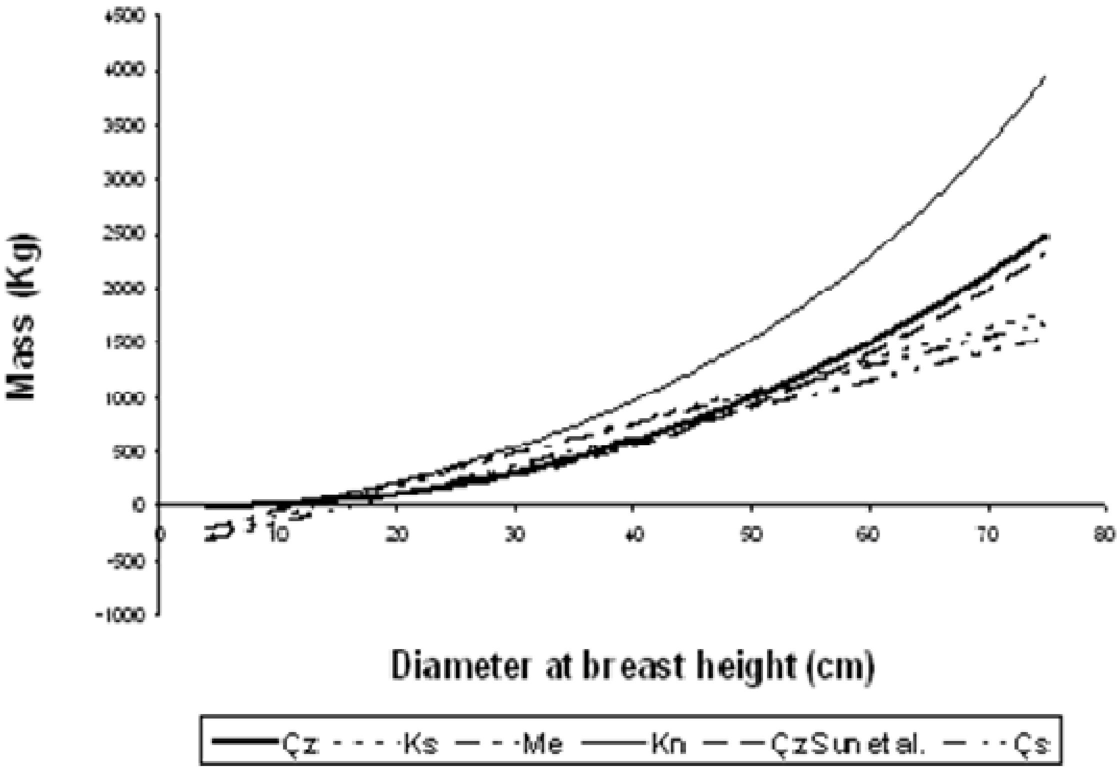


**Figure 1.** Biomass changes according to diameter at breast height in single trees in terms of species.

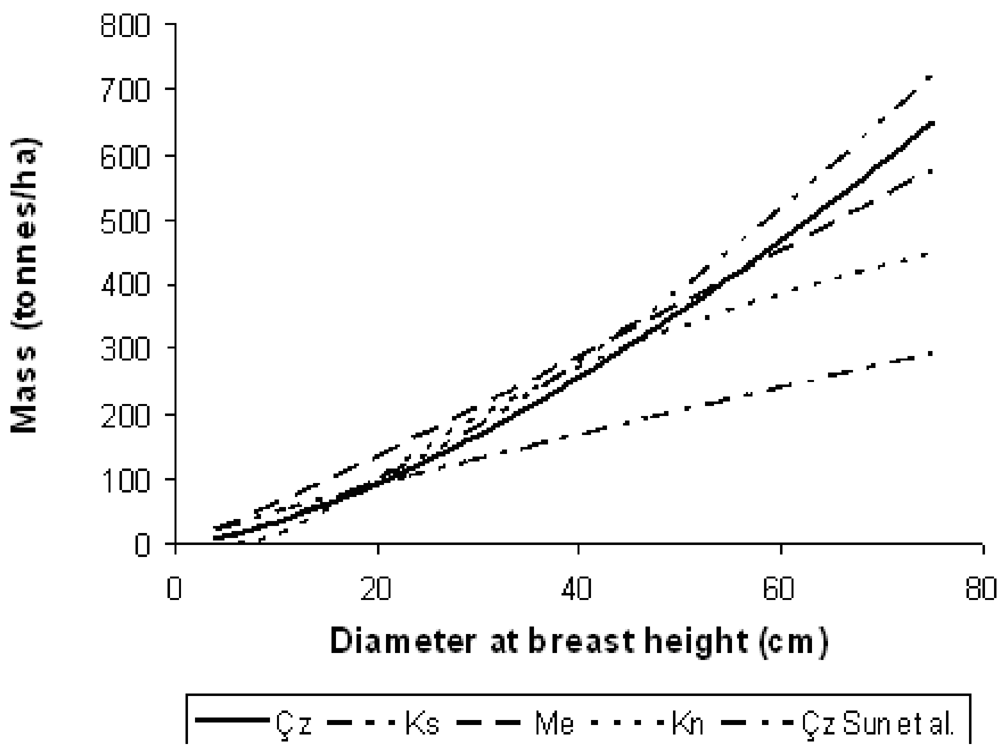


**Figure 2.** The change of stand biomass values according to diameter at breast height in terms of species.

**Table 6.** Arranged single tree biomass equations.

| Tree species | Equation |
|---|---|
| Scots pine (Çs) (Uğurlu et al.) | $TB = -406.27916 + 26.13597d$ |
| Calabrian pine(Çz) (Sun et al.) | $TB = -0.88492 + d^{2.2672}$ |
| Beech (Kn) (Saraçoğlu) | $\text{Log } TB = 2.86264 + 0.012441d - 14.90987d^{1}$ |
| Oak (M) (Durkaya) | $TB = -302.193 + 26.56596d$ |
| Chestnut (Ks) (İkinci) | $TB = -376.794 + 28.7981d$ |

**Table 7.** Arranged stand biomass equations.

| Tree species | Equation |
|---|---|
| Calabrian pine(Çz) (Sun et al.) | $TB = 0.81535d^{0.881143}$ |
| Beech (Kn) (Saraçoğlu) | $\log TB = 2.834483 + 0.0005311d - 16.82563d^{1}$ |
| Oak (M) (Durkaya) | $\log TB = 3.705655 + 1.09609 \log d$ |
| Chestnut (Ks) (İkinci) | $\log TB = 3.04224 + 1.50159 \log d$ |

Comparison of the models shows that calabrian pine stands provided dry weight and energy production capacity as much as hardwood stands. This means that calabrian pine stands can be managed for energy industry.

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