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Biomass Expansion Factor (BEF) and Carbon Stock for Brant's Oak (*Quercus brantii* Lindl.) Forests of West-Iran

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Abstract - Investigating a tree's biomass can provide basic information about forest carbon stock. The Biomass Expansion Factor (BEF) is a variable for estimating carbon stock of forests. The aim of this study was to analyse the Above Ground Biomass (AGB) allocation, developing the BEF and carbon stock for two vegetation forms of Brant's Oak (*Quercus brantii* Lindl.) based on forest inventory data. BEF is defined as the ratio of AGB to crown volume variables. The study data were taken from 30 trees that include 16 individual trees with single stem and 14 coppice shoots located in West-Iran. The trees selected were felled and separated into different components including: bole, main branches, lateral branches, twigs and leaves. The fresh weight of the trees was obtained with a portable hanging scale and several samples were taken from each tree component. The results of this study showed significant differences between component biomass proportions of the two vegetation forms of Brant's Oak trees and determined average biomass and carbon content of the forms studied. We also conclude that BEF of Brant's Oak could be improved by applying crown variables. According to the results, BEFs are tree-size dependent variables. Finally, this study indicates that age-dependent BEFs cannot be applied to conditions where stand development deviates from the conditions that in which the BEFs were developed.

Keywords - canopy volume; carbon; coppice; open forest; single stem; Zagros.

Introduction

CO_2 is one of the main greenhouse gases and the main reason for the global warming issue. Widespread concern about global warming and climate change has brought about an international agreement to reduce the amount of emission of this gas into the atmosphere. Under the United Nations Framework Convention on Climate Change (UNFCCC), most of world's countries are required to prepare a national inventory of greenhouse gas emissions and sequestration. Forest trees are the major terrestrial carbon pool and their ability to sequester carbon in their tissues has captured the interest of the world's governments. Estimating the biomass of trees is useful to assess forest structure and its condition (Chavé et al. 2003), carbon stocks and carbon sequestration in their biomass components and it is an indicator of whole site productivity (Návar 2009).

Currently, the methods used to calculate the biomass and carbon stock of trees are different (IPCC 2003). There are two approaches for estimating the above-ground biomass (AGB) of trees: a direct approach using allometric equations, and an indirect approach using biomass expansion factors (BEF). The indirect method is based on factors developed at stand level, and cannot be used to estimate biomass of individual trees (IPCC 2003). On the other hand, one of the methods used to convert field measurements of trees (forest inventory data) to stand biomass values is based on BEF (Soares and Tome 2004). These are mostly based on forest inventory information, by transforming the diameter, height or volume data into biomass estimates (Somogyi et al. 2006).

Sharp et al. (1975) were probably the first persons to use a constant BEF to estimate forest biomass. In their study a BEF of 2.0mg/m^3 was used to calculate the forest biomass in North Carolina, USA, based on forest inventory data. However, other studies indicated that the BEF is not constant (Guo et al. 2009). Since BEF is easier to use than biomass equations, the former is preferred (Johnson and Sharpe 1983). The aim of using such a factor is to take advantage of many tree-volume functions that are already available (West 2009). BEF application may vary in different projects. In some studies, single default values are often used, such as Kauppi et al. 1995. However, these factors may depend on the species, growth phase and site conditions (Satoo and Madgwick 1982). Therefore, calculations of BEF under specific conditions are to be preferred

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(Lehtonen 2004). Muukkonen (2007) also made a compilation from several published studies and introduced some generic equations for volume and biomass in Europe.

In most European countries, greenhouse gas inventories are largely based on converting tree volume data from National Forest Inventories (NFI) to biomass using BEFs (Teobaldelli et al. 2009). However, BEF should be developed locally; otherwise, biased biomass estimation will be made (Lethonen 2005). NFI data can be processed in the tree level in order to provide accurate estimates of stand biomass. However, BEFs are still needed in published NFI results in which biomass is not estimated and as a complement of growth models that do not include biomass predictions (Soares and Tome 2012). In some research, BEF is defined as the ratio of the total AGB of trees to the biomass of the commercial timber. One example of this type of approach is the study by Levy et al. (2004) about BEF for coniferous tree species in Britain. In their study, BEF varied between 1.04 and 2.32, with a mean of 1.43 and tree height accounted for 45% of the variance in BEF in a logarithmic regression. The BEF was defined as, BEF=W/V, where W(mg) is AGB (including leaves, twigs, branches and stem) of the trees and V(m^3) contains the volume of sellable woody parts of the trees.

Chhabra et al. (2002) used BEF as a function of stock volume growth. Lehtonen et al. (2004) described stand-level BEFs, by converting stem volume to tree-component biomass (foliage, branches, stem wood, bark, stump, coarse roots and small roots). Lehtonen et al (2007) also suggested BEF estimation is an uncertain approach and found it an age-dependent approach. It is also sensitive to the dependencies among errors. Most of the uncertainty in estimating BEFs is related to uncertainty in applied biomass and volume models. Peichl and Arain (2007) measured AGB of forest trees in different ages and found that individual trees' BEFs for leaves, branches and roots change with the stand age. So, they developed experimental functions to relate those factors to the tree's age. Pajtik et al. (2008) presented the allometric equations and BEFs for young Norway (*Pice abies* L.) spruce trees (less than 10 years old) from natural regenerations in Slovakia. In other studies, Soares and Tome (2012) provided BEF for *Eucalyptus globules* Labill. stands in Portugal. They analysed changes in BEF by stand variables. Strong relationships were observed between BEF and stand age, basal area, volume and total height.

Brant's Oak (*Quercus brantii* Lindll.) is the main tree species in West-Iran. It is the dominant forest species in all of the southern zone of the Zagros area in the Irano-Turanian phytogeographical region. Although Brant's oak is important in ecological terms and carbon sequestration discussions, there are no available studies about biomass or carbon allocation or other similar studies related to this species. Because of the lack of general biomass functions for Brant's Oak in West-Iran, the aim of this study is to develop BEF for above-ground components in two common vegetation forms of Brant's Oak in the Zagros region of Iran. These equations could be applied to estimate the amount of carbon stored in this type of forest. These kinds of studies are able to help forest managers to estimate the stored carbon in Brant's oak stands with different components using forest inventory data.

Materials and Methods

Site description

The study was conducted in the Zagros region in West-Iran, which covers a vast area of the Zagros Mountains that is classified as semi-arid and open forests. The area selected for this study with a surface of 90ha is located between 50º 59′ 00″-50º 59′ 54″ E and 31º 14′ 20″-31º 15′ 24″ N in Chaharmahal and Bakhtiari province (Fig. 1). The mean annual rainfall of the area is 567mm and the mean annual temperature is 15.5ºC. The main soil types of the study area are clay and clay-loam.

Brant's Oak is one of the most important tree species of Iran's western forests with an area of 3,500,000ha that covers the Zagros Mountains and makes a vast distributed pure and mixed oak community from 1,000 to 2,000m above sea level and extended from the North-West to the South-West of the country. These oak stands mixed with *Juniperus excelsa* M. Bieb at higher altitudes and with *Amygdalus scoparia* Spach., *Pistacia Atlantica* Desf. and *Acer monspessulanum* L. at lower altitudes. Due to human impact, only 7% of the oak forests is considered as high forests (trees with single stem), while the remaining 93% is coppice stands.

Tree selection

Thirty, one-hectare sample plots were established in the study area (Fig. 1). In each plot diameter at breast height (DBH), total height and crown diameter of all trees were measured. Trees were selected based on random sampling. Therefore 11 classes for individual trees with single stem based on DBH and 7 classes for coppice shoots based on crown diameter were identified with an equal proportion of trees in each class. Then, one or two of the trees were selected in each class. Thus 30 trees including 16 single-stem trees and 14 coppice

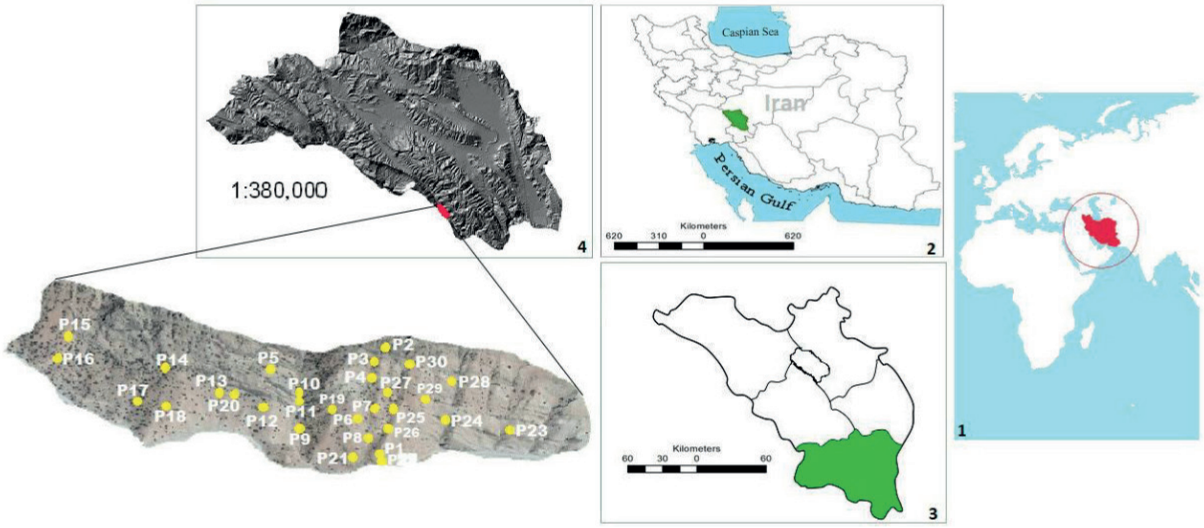

Figure 1 - Study area and location of sample plots.

shoots were selected to fell. Before felling, DBH, total height, crown diameter, crown height and shoot density of the trees selected were measured immediately.

Felling the trees and sampling procedures

Field work took place over 4 weeks in July and August, before leaves fall in autumn. For this purpose, sampled trees were felled and separated into different components including: trunk, main branches (diameter > 5cm), lateral branches (diameter between 1 and 5cm), twigs (diameter < 1cm) and leaves. All diameters were measured over the bark. Then fresh weights of all compartments were measured directly in the field using a portable spring scale (with 0.5kg accuracy).

Sample processing

The fresh weights of all felled tree components were measured. Thereafter, we randomly selected 30 leaves, 10 twigs (with 20cm length), 5 sample discs of branches with different sizes and 1 disk (with 5cm thickness) from the trunk (Losi et al. 2003).

The fresh weight of samples was measured immediately in the field. Afterward, to prevent any change in the quality of the samples, all labelled samples were transported to the nearest lab inside special bags. Then, all samples were dried at 80°C for 24 hours until the weight of samples became stable.

Equation (1) was used to determine dry weight of the components (Heidari Safari Kouchi et al. 2017).

$$WDc = \frac{WFc * WDs}{WFs} \qquad (1)$$

Where: WDc is the dry weight of each component of the tree, WFc is the fresh weight of each tree, WDs is the dry weight of each sample and WFs is the fresh weight of each sample.

Biomass expansion factor calculation

Paying attention to the growth form of Persian oak species in the Zagros habitat, trees trunks are not high and cylindrical. Actually, the tree trunk does not have a recognisable shape. Also, the volume of the trunk is not noticeable against the biomass of the crown (main branches, branches, twigs and leaves). In other words, the tree crown is important in biomass calculations. This is visible in Figure 2. So, we used crown volume instead of the oak trunk in the calculations.

Canopy volume was calculated by Crown form factor (C_f) Value, using equation (2) (Forrest Frank 2010):

$$C_v = (C_f) \times (C_{th}) \times (A_{amcs})^2 \qquad (2)$$

Where: C_v is the crown volume, C_f is the crown form factor and A_{amcs} is the average maximum crown spread.

Finally, a BEF for each form of the trees was calculated by using equation (3).

$$BEF = \frac{(\sum(AGB)_i / X_i)}{n} \qquad (3)$$

Where: AGB is above-ground biomass of each tree. X_i in this study is crown volume (Cv, which could be different in other studies depending on the study species characteristics) and n is the number of trees used to calculate the BEF (Lehtonen et al. 2004).

Table 1 - Biomass, carbon fraction and carbon content of two forms of Brant's Oak in different components (mean ± S.E.).

	Component	Biomass (kg)	Carbon Fraction (%)	Carbon (kg)
Individuals with single stem	Leaf	14.7 ± 2.8	47.1	6.9 ± 1.3
	Twig	15.6 ± 2.6	48.1	7.5 ± 1.2
	Lateral Branches	89.4 ± 25.5	48.6	43.4 ± 12.4
	Main Branches	115.6 ± 24.8	48.4	55.9 ± 19.6
	Bole	96.4 ± 23.0	48.6	46.8 ± 11.2
	Stump	28.2 ± 8.1	48.6	13.7 ± 3.9
	Total	359.9 ± 82.9		174.2 ± 46.3
Coppice Shoots	Leaf	9.8 ± 2.2	47.1	4.6 ± 1.0
	Twig	7.8 ± 1.6	48.1	3.7 ± 0.8
	Lateral Branches	19.9 ± 3.7	48.6	9.7 ± 1.8
	Main Branches	38.4 ± 9.1	48.4	18.5 ± 4.4
	Bole	54.6 ± 14.7	48.6	26.5 ± 7.1
	Stump	13.7 ± 3.9	48.6	6.7 ± 1.9
	Total	144.2 ± 34.0		69.8 ± 16.5

Calculation of the carbon stock

Carbon percent (C_c %) of the samples was obtained by burning the samples in an electric kiln and the carbon stock of the tree components investigated by using equation (2) (Heidari Safari Kouchi et al. 2017).

$$W_c = \frac{w_{dc} * C_c\%}{100} \qquad (4)$$

Where: Wc is the weight of carbon for each component and W_{dc} is the dry weight of each component of the trees.

Data analysis

Normality of data was tested with the Kolmogorov-Smirnov test. Root mean square error (RMSE) and bias were also used to evaluate the goodness of model fit. To compare the observed biomass with predicted biomass, paired sample t-tests were used. Significance between the means was evaluated at the ϱ= 0.05 and 0.01 probability levels. All computations were performed using the statistical software SPSS-22.

Results

Results are presented separately for individual trees with single stem and coppice shoots. Table 1 shows a summary of the descriptive statistics of the variables analysed. The mean of trees biomass expressed as dry mass in individual trees with single stem is calculated as about 359.9kg in comparison to the coppice shoots with 144.2kg. Measured carbon fraction was between 47.1% and 48.6% for the whole dry-component samples. Carbon content of individual trees with single stem and coppice shoots were 174.2kg and 69.8kg respectively.

The tree biomass is normally divided into the above-ground components including stump, bole,

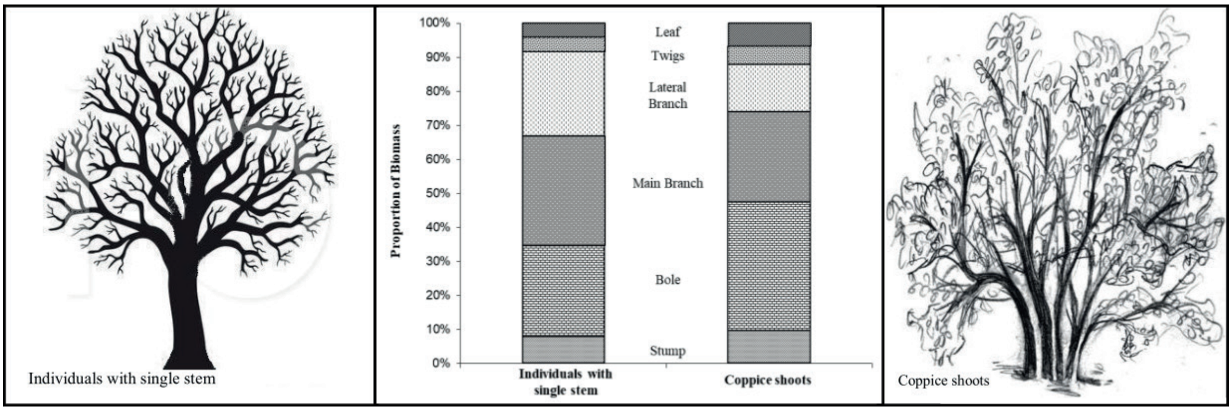

Figure 2 - Proportion of different components biomass in two vegetation forms of Brant's oak.

Table 2 - Test statistics of the BEFs based on Crown Volume from individual trees with single stem. Bias refers to the mean of differences between observed and predicted diameters in percentage (%) from mean biomass. RMSE refers to the root mean squared error. * refers to < 0.05 and ns to non-significant.

Component	Actual Biomass (kg)	Predicted Biomass (kg)	Sig.	BEF	%Bias	%RMSE
Leaf	14.7 ±2.8	20.8 ±5.1	*	0.15	41.56	110.51
Twig	15.6 ±2.6	23.2 ±5.7	*	0.17	49.11	113.23
Lateral Branches	89.4 ±25.5	72.9 ±18.1	ns	0.53	-18.34	52.38
Main Branches	115.6 ±24.8	83.2 ±20.7	ns	0.60	-28.06	80.12
Bole	96.4 ±23	100.8 ±25	ns	0.73	4.45	29.34
Total AGB	359.9 ±82.9	325.7 ±80.9	ns	2.37	-9.51	22.81

branches and foliage. The maximum biomass in individual trees with single-stem components was calculated as 115.6kg for main branches, while in coppice-shoot components tree bole showed the maximum biomass with 54.6kg (Table 1). According to the results, the ratio of branch biomass (main and lateral) in individual trees with single stem was more than that of in coppice shoots, whereas the proportion of stump and trunk biomass in coppice shoots was more than those in individual trees with single stem (Fig. 2). The canopy biomass including foliage and branches was heavier than the trunk and stump biomass for both growth forms of oak trees. The amount of foliage biomass, including twigs and leaves, is less than other components (Fig. 1).

According to Fig. 3 the foliage biomass in large trees is less than those in small and medium size trees. On the other hand, the trees' AGB was increased by tree-size increasing but trees' non-woody part biomass (foliage) to the total AGB ratio decreased with tree-size increase for both tree forms of Brant's Oak.

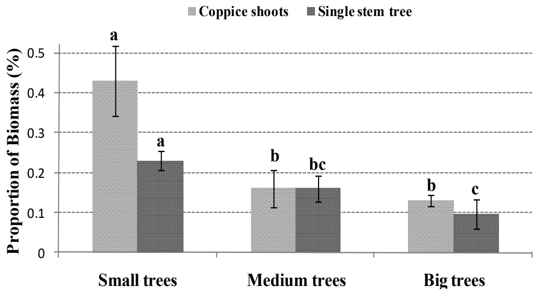

Figure 3 - Proportion of trees non-woody (foliage) parts biomass to the total above-ground biomass. The bars are standard errors and the different letters over the columns indicate significant differences ($\varrho < 0.05$).

Also, calculating the AGB for two vegetation forms of oak trees were surveyed separately. The Kolmogorov-Smirnov normality tests indicated that the BEF for all components was distributed normally.

Individual trees with single stem

For all components of the trees, BEFs were calculated based on crown volume. The BEFs, bias and RMSE of the biomass estimated for all components of Brant's Oak trees are summarised in table 2. The BEF for the total AGB of individual trees with single stem was 2.37kg/m^{-3}. According to BEFs, the correlations of tree-component biomass with the different quantitative variables were weaker in comparison to the crown volume. On the other hand, the correlations between the component biomass and crown volume were higher than other variables. Also, the most observed difference between the results was related to the foliage (leaves and twigs). The BEFs describing AGB of components, especially foliage showed higher RMSEs and Bias than those for other tree components. On the other hand, for the non-woody components, the BEFs did not show enough accuracy (Table 2). The paired sample t-test exam results, of BEFs ratio based on crown volume, showed no significant difference between the estimating method and actual biomass measurement in individual trees with single stem, except the foliage.

Coppice Forests

The calculation of BEFs for Coppice shoots of Brant's Oak trees showed that composite variables of "Crown diameter x crown height x shoot density" provided the most acceptable models to estimate the trees biomass. In BEF calculations based on this variable, the observed biomass of all components of oak trees did not have significant difference with its estimation by predicted biomass (Table 3). The BEFs for the total biomass of coppice shoots was 7.2kg/m^{-3}. The RMSE and bias of BEFs developed for AGB of coppice shoots were less than those for trees with single stem.

The relationship between BEFs and diameter at breast height (DBH) of individual trees with single stem is shown in Figure 4 (part a), while Figure 4 (part b) shows the relationship between BEFs and crown diameter for coppice shoots. The values of BEFs increase with increasing the size of AGB. These relations are consistent for tree boles with single stem and twig and leaf in two vegetation forms of Brant's Oak, but not consistent for branches. The highest values of the BEFs were found for AGB depending on the size of the tree, while the lowest values were found for foliage. Similarly, there is a relationship between the variability of BEFs between trees and tree size. Generally, the accuracy of estimated BEFs for all component biomass increased with increase of tree size. The results of relationship of BEFs with other tree variables like total height and crown height is weaker in comparison with DBH and crown-diameter variables.

Discussion

Biomass partitioning

Related theories to carbohydrate allocation rules can be used to quantify biomass of trees in various scales, e.g. tree, stand and region (Lethonen 2005). However, the partitioning of carbohydrates for tree growth of different biomass pools and their respiration is not adequately known (Lacointe 2000). The optimality concept (Hari et al. 1990) states that trees allocate carbohydrates in such way that they maximise their annual photosynthesis with restriction of carbohydrate amount. According to the theory of allocation priority, trees also perform carbohydrate allocation prioritisation. Oliver and Larson (1996) affirmed that priority of carbohydrate allocation is given to maintenance respiration, which is followed by fine root and foliage production, flowering, height growth and diameter growth, although recognising that the order of the priority may change temporarily.

These concepts lead to the assumption that the biomass proportions of trees are dependent on various environmental conditions, genetics and also depended on tree age (Lethonen 2005). Forest trees usually compete with their neighbours for essential resources, e.g. sunlight, water, and nutrients (Simon and Edmund 2000). Plants always adjust their above- and below-ground structure and biomass to environmental changes. The results of this study showed that the relative proportion of the bole biomass in the coppice shoots is more than other components and also more than those in individual trees with a single stem, whereas the canopy biomass in coppice shoots is smaller than those in trees with a single stem. Nevertheless, it would be expected that the bole biomass would be different in oaks which are coppiced from those in single stem oaks, due to differences in architecture. Coppice shoots have different stems because of their sprouting type.

Another important factor for biomass partitioning in tree species is tree age. With the increase in age, the proportion of stem wood in the biomass becomes more obvious (Peichl and Arain 2007, Nogueira et al. 2008, Sanquetta and Silva 2011). Wang et al. (2011) explained that the relative contribution of canopy-part (living branches and foliage) biomass decreased with increasing tree size. In our study branch biomass (main and lateral branches) had a significant role in AGB of oak trees especially in high (single stem) forests. The proportion of canopy biomass increased with increasing tree size except the foliage biomass. These findings are in accordance with some research that explained how in mature trees the rate of stem growth decreases relative to that of foliage (Waring and Schlesinger 1985), while biomass accumulation in stem increases (Wieser 2007). This is also consistent with the results of Kantola and Makela (2006), which showed that in young Norway spruce the proportion of branch biomass increases and needles decrease with increasing tree height inside the spread crowns. On the other hand, trees growing in open spaces tended to have widespread crowns and large biomass in branches and leaves in contrast to the tree's bole. Kantola and Makela (2006) found that Norway spruce trees initially allocate most percentage of their biomass to branches, while allocation to foliage decreases.

Table 3 - Test statistics of the BEFs based on "Crown diameter × crown height × shoot density" variables of coppice shoots. Bias refers to the mean of differences between observed and predicted diameters in proportional terms (%) percent from the mean biomass. RMSE refers to the Root mean squared error.

Component	Real Biomass (kg)	Predicted Biomass (kg)	Sig.	BEF	%Bias	%RMSE
Leaf	9.8 ± 2.1	10.1 ± 2.1	ns	0.6	2.86	31.92
Twig	7.8 ± 1.6	8.7 ± 1.8	ns	0.5	12.46	31.08
Lateral Branches	18.6 ± 3.7	18.6 ± 3.9	ns	1.1	0.06	31.82
Main Branches	38.1 ± 9.1	29.8 ± 6.3	ns	1.8	-21.92	42.87
Bole	56.2 ±14.6	44.6 ± 9.4	ns	2.6	-20.57	49.66
Total AGB	144.1 ± 34.1	122 ± 25.7	ns	7.2	-15.34	34.80

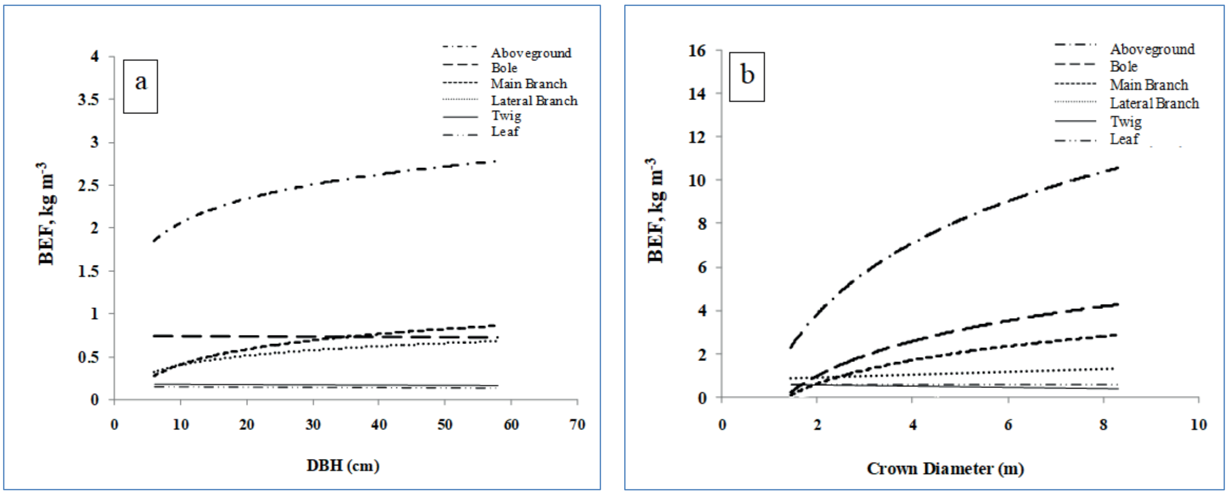

Figure 4 - Relationship between BEFs and DBH for individual with single stem (a) and crown diameter for coppice shoots (b) of Brant's Oak as a function of tree size.

Biomass expansion factor

In this study we used crown variable in BEF ratio, because of the tree-crown importance in semi-arid Mediterranean Brant's Oak measurements. The crown of trees encompasses the main proportion of AGB in two vegetation forms of Brant's Oak.

The results indicated that BEFs are tree-size dependent (Fig. 3). The main and lateral branch BEFs increase with tree size. On the other hand, for the BEFs, the trend is less steep although a constant increase is also recorded. Lehtonen et al. (2004) observed that BEF for total AGB increased in beech (*Fagus sylvatica* L.) and pine trees (*Pinus* spp.) but diminished in oak and spruce trees with incremental DBHs. These relationships are consistent for bole, twig and leaf biomass.

The increasing trend for BEFs leads to the conclusion that with increasing tree size the proportion of crown volume decreases compared to the proportion of the AGB. The increasing trend of BEFs is a result of changes in crown density with changes in tree size. These findings are in accordance with Návar (2009) who described BEFs for tree components on different sizes. The results obtained from his study and another study (Brown et al. 1989, Brown and Iverson 1992) show the necessity to develop specific BEFs for each region and forest type in the West-Iran forests. The general models of total AGB should be carefully used in specific areas or carbon projects (Noble et al. 2000).

Conclusions

The models developed in this study are recommended only when DBH is between 10 and 60cm in high forests. For the coppice shoots the functions for BEFs can be applied for woodlands with crown diameter ranging from 1.5 to 8m. The increase value for %RMSE and relative bias in leaf and twig leads to the conclusion that the BEF was not a good biomass predictor for non-woody components of individual trees with single stems. The current expansion factors, which are about foliage, can be applied for rough estimation of the biomass of these components. In summary, we developed simple predictive equations for determination of Brant's Oak biomass based on crown variables. These equations provide a useful tool for rapid estimation of AGB for two vegetation forms of Brant's Oak at the stand level.

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