# Estimation of leaf area index and assessment of its allometric equations in oak forests: Northern Zagros, Iran

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**ABSTRACT**: The focus of the present study is the estimation of leaf area index (LAI) and the assessment of allometric equations for predicting the leaf area of Lebanon oaks (*Quercus libani* Oliv.) in Iran's Northern Zagros forests. To that end, 50 oak trees were randomly selected and their biophysical parameters were measured. Then, on the basis of destructive sampling of the oak trees, their specific leaf area (SLA) and leaf area were measured. The results showed that SLA and LAI of the Lebanon oaks were 136.9 cm·g$^{-1}$ and 1.99, respectively. Among all the parameters we measured, the crown volume exhibited the highest correlation with LAI ($r^2$ = 0.65). The easily measured tree parameters such as diameter at breast height did not show a high correlation with leaf area ($r^2$ = 0.36). Our obtained moderate correlations in the allometric equations could be due to the fact that branches of these trees had been pollarded by the local people when the branches were only 3 or 4 years old; therefore, the natural structure of the crowns in these trees might have been damaged.

**Keywords**: allometric relationships; destructive sampling; leaf area index; *Quercus libani* Oliv.; specific leaf area

One of the most commonly used parameters for the analysis of canopy structures is leaf area index (LAI) (Beadle 1997; López-Serrano et al. 2000; Davi et al. 2009) which is defined as the projected one-sided leaf area per unit ground area (Deblonde et al. 1994). This parameter determines the amount of the plant – atmosphere interface; hence, it plays a crucial role in the process of exchanging energy and mass between the canopy and the atmosphere (Weiss et al. 2004). Methods for the estimation of LAI are mainly categorized as direct and indirect methods (Kussner, Mosandl 2000). It is difficult to use direct methods, including harvesting, allometry and litter collection (Bréda 2003). Then, to obtain the LAI of a stand, a destructive sampling should be done through harvesting the total leaf biomass of the trees to generate the total dry weight of the foliage (Arias et al. 2007). On the other hand, indirect methods, in which leaf area (LA) is inferred from observations of another variable, are generally faster and amendable to automation, and thereby allow for a larger spatial sample to be obtained (Jonckheere et al. 2004). Unfortunately, the lack of the required equipment for doing such newly established researches in Iran in the field of natural resources has placed obstacles in the way of researchers to estimate LA through using indirect methods (Adl 2007). To determine LAI, it is essential to have an exactly accurate estimation of the total LA of a tree. Though direct methods are of very high accuracy, they have the drawback of being extremely time-consuming; consequently, they make large-scale implementation only marginally feasible (Jonckheere et al. 2004). Another important aspect of tree researches is the task of figuring out an appropriate allometric relationship between LA and other biophysical parameters of trees such as diameter at breast height (DBH), tree height, crown surface area, and litter mass (Vyas et al. 2010). These relationships relating to litter mass and DBH can be used to estimate LAI by having the specific leaf area (SLA) (Gower et al. 1999). Many studies have shown a relationship between LAI and these parameters for different species (López-Serrano et al. 2000; Turner et al. 2000; Tobin et al. 2006; Arias et al. 2007; Pokorný, Tomášková 2007; Vyas et al. 2010). However, allometric equations have rarely been investigated in oak forests so far (Čermák et al. 2008; Babaei-Kafaki et al. 2009).

The oak forests of Baneh (a small town in Iran) are among the most important natural ecosystems located in the Northern Zagros Mountains, and despite their importance, they have not been studied comprehensively so far. These forests are the richest in the number of oak species in comparison with forests of central and southern Zagros, and Lebanon oak (*Quercus libani* Oliv.) is one of the dominant tree species in these forests. Although the policy of Iran's Forest and Rangeland Organization is to conserve these forests, due to the lack of social acceptance and participation, this policy has not been successfully implemented yet (Ebrahimi-Rastaghi 2001; Ghazanfari et al. 2004). Consequently, traditional exploitations by local communities living in these regions have still continued. Long-term heavy dependence of forest dwellers upon forests resulted in the construction of special relationships named traditional forestry (Valipour et al. 2009). Because of grinding poverty of the local people, the villagers cut branches off oak trees as fodder supply. This process is as follows: each traditional owner of an area of the forest divides his forest area into 3 or 4 sections; every year in the late growing season, all branches of trees in one of these sections are pollarded; thereafter, the leaf-bearing pollarded branches will be stored to be used in winter. The principal objective of this traditional forest management pursued by forest owners in the region is the production of fodder for domestic animals, firewood and timber (Ghazanfari et al. 2004). In addition, grazing prevents natural regeneration of trees (Ebrahimi-Rastaghi 2001) and leads to old even-aged stands in the forests; hence, the stability of the ecosystem would be threatened. Under present circumstances, basic information such as biomass, LAI and its allometric relationships is needed to choose a correct forest management strategy before the valuable forests of this region are totally destroyed.

This article is aimed at estimating LAI and SLA with the use of a direct method (destructive sampling) and at assessing useful allometric equations to predict LA of Lebanon oak in Northern Zagros forests in Iran. We do this by addressing the following questions: Can biophysical parameters such as DBH, basal area, tree height, crown length, crown projected area, and crown volume predict the tree leaf area? And which of these parameters can be a better predictor to estimate the leaf area?

## MATERIAL AND METHODS

### Study area

Our investigated areas are Armardeh forests located in the southwest of Baneh and northwest of Kurdistan province, Iran. These forests extend from 35°51'40" to 35°57'55"N latitude and from 45°44'20" to 45°49'55"E longitude, with a mean altitude of about 1,620 m a.s.l. *Quercus libani*, *Quercus infectoria* and *Quercus brantii* are the most dominant tree species of our areas of investigation. Generally, the watershed of Baneh is a highland region with long, snowy, and cold winters and mild summers. The ombrothermic curve of the monthly sum of precipitation and the average temperature for 2001–2010 indicate that the dry period may occur during five months of the year. During this decade, the mean annual precipitation was 690 mm, most of which was in late autumn to early spring. Furthermore, the maximum and minimum temperatures in the hottest and coldest months of the year were 29.3°C and 4°C, respectively.

### Data collection

At the beginning of our study, an appropriate stand of the abovementioned area was selected, and the goal of this research was simply explained to the local owner of that stand in order to get his agreement for participation. In the second stage, to estimate the density of trees, three parts of the desired stand were chosen as its representatives, and using GPS, the area of these three parts was determined to be approximately 13 hectares. Then, types of species and total trees in this area were evaluated. The results of the inventory for the identified species of trees showed that the densities of the total trees, *Quercus libani* and *Quercus infectoria* were 370, 302, and 68 trees·ha$^{-1}$, respectively. In the third stage, 50 Lebanon oaks were randomly selected, and their biophysical parameters such as DBH, basal area, tree height, crown length, crown projected area, and crown volume were measured. It should be noted that there are various methods for measuring the LAI of a tree.

The direct approaches, not commonly used in such studies, are very time-consuming; moreover, for the case of LA estimation, they are expensive and destructive to the sample (Vyas et al. 2010). However, in view of the fact that branches and leaves of the oak trees in our study area had been pollarded by local people, we utilized a direct method to estimate LAI. Thus, in the fourth stage, the numbers of branches of sample trees were determined after they had been totally pollarded by the local owner. From each sample tree, 20 branches were selected in different directions, and also from all parts of the crown randomly; then total leaves of these branches were counted. To evaluate the percentage of moisture and leaf area, 10–15 leaves from each branch were randomly selected. The samples were put into paper covers and transferred to the laboratory. We did not use an area-to-weight relationship to estimate projected leaf area, but we preferred to measure the leaf area of random samples for each tree. In the laboratory, projected leaf areas of the fresh leaf samples were determined using a leaf area meter (Delta-T Devices Ltd., Burwell, Cambridge, England). After placing them in an oven at 80°C for 48 hours, the dry weight was measured. To weigh the leaves, a scale with the accuracy of 0.01 g was used. Subsequently, the average SLA, defined as the one-sided leaf area per unit of leaf dry weight, was calculated.

### Data analysis

When preparing the crown images of sample trees in four directions, the tree crown was considered to have an approximately oval shape (Fig. 1). Thus, the volume of the sample trees crown was calculated as follows:

$$V_c = \frac{4}{3}\Pi \times \frac{d_{c_1}}{2} \times \frac{d_{c_2}}{2} \times \frac{l_c}{2} \qquad (1)$$

where:

$V_c$ – volume of the tree crown ($m^3$);

$d_{c_1}$, $d_{c_2}$ in terms of m – two diameters of the crown based on the measurements made along two perpendicular directions,

$l_c$ – crown length (m).

LAI can be calculated using the following equation:

$$\text{LAI} = \frac{d \times \sum_{i=1}^{n} A_L}{n \times 10{,}000} \qquad (2)$$

where:

$\sum_{i=1}^{n} A_L$ – total projected one-sided area of leaves for 50 chosen sample trees ($m^2$),

$d$ – tree density ($\text{tree}\cdot\text{ha}^{-1}$),

$n$ – number of sample trees (50 trees).

Subsequently, four regression models were used, and the best models were chosen based on the highest determination coefficient ($r^2$) while $r^2$ was also tested for significance:

Linear: $Y = a + bX$ (3)

Quadratic: $Y = a + bX + cX^2$ (4)

Exponential: $Y = \exp(a + bX)$ (5)

Multiplicative: $Y = aX^b$ (6)

where:

$X$, $Y$ – independent and dependent variables, respectively,

$a$ – interception of the line with $Y$ axis,

$b$, $c$ – regression coefficients (Zar 1996).

Independent variables in this paper are DBH, basal area, tree height, crown length, crown projected area, and crown volume, and the dependent variable is the projected leaf area for each tree.

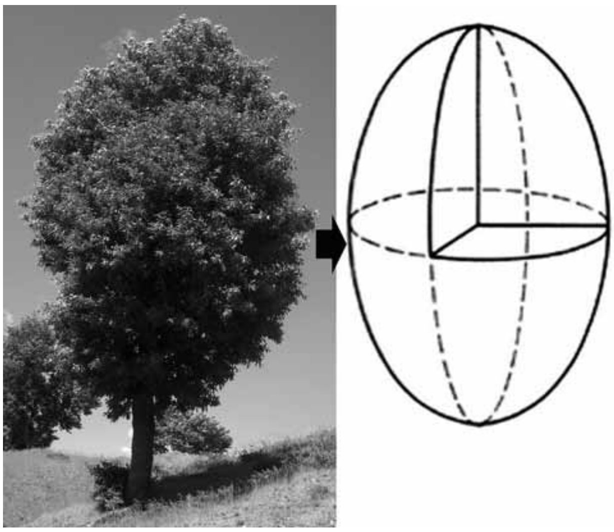

Fig. 1. The oval shape of the tree crown in the study area

## RESULTS AND DISCUSSION

All the parameters of fifty sample trees are documented in Table 1. The range of SLA is between 63.6 and 213.4 $cm^2\cdot g^{-1}$. The average projected area

Table 1. The parameters of the sample trees of Lebanon oak ($n$ = 50)

| | Mean | Maximum | Minimum | SE |
|---|---|---|---|---|
| DBH (cm) | 28.10 | 49.40 | 13.00 | 1.20 |
| Basal area ($m^2$) | 0.27 | 0.77 | 0.05 | 0.02 |
| Height of tree (m) | 9.50 | 12.90 | 4.50 | 0.25 |
| Crown projected area ($m^2$) | 6.00 | 15.10 | 1.10 | 0.48 |
| Crown length (m) | 6.60 | 10.60 | 1.50 | 0.29 |
| Volume of crown ($m^3$) | 28.10 | 90.10 | 2.30 | 2.89 |
| SLA ($cm^2 \cdot g^{-1}$) | 136.90 | 213.40 | 63.60 | 4.56 |
| Projected leaf area of sample tree ($m^2$) | 63.52 | 226.74 | 25.47 | 5.24 |

DBH – diameter at breast height, SLA – specific leaf area, SE – standard error

of leaves is 63.52 $m^2 \cdot tree^{-1}$. Therefore, considering the tree density of Lebanon oak in the study area, which is 302 $trees \cdot ha^{-1}$, LAI of Lebanon oak would be 1.99. When conducting a similar study on forests of southern Zagros, the trees of which were not pollarded by the local people, Adl (2007) found the value of 171.2 $cm^2 \cdot g^{-1}$ for two-sided SLA of *Quercus brantii*. Moreover, his results also showed that LAI for this species, with a density of 90 $trees \cdot ha^{-1}$, is equal to 1.1, which is less than the value we calculated for *Quercus libani* Oliv. It is a point of note that, in view of the fact that the local residents cut the branches off oak trees in a period of 3 or 4 years, the estimated value of LAI for the explored forests is only for the growth of branches within this time period.

In Fig. 2, allometric relationships were developed between the leaf area and the biophysical parameters such as DBH (a), basal area (b), height of the tree (c), crown length (d), crown projected area (e), and crown volume (f). They were highly significant ($P < 0.001$). As shown dotted in a model of Fig. 2, the distribution of the leaf area increases at diameters of about 25 cm or more; this observation is also clearly true of the other models. It should be pointed out that replacing the basal area with DBH did not increase the determination coefficient (model b). According to model (f) of Fig. 2, the value of $r^2$ in a bivariate regression model between the crown volume and the leaf area was 0.65, which was the highest coefficient of determination among the abovementioned models. It is worth mentioning that models (a) and (b) are multiplicative ones; models (c), (e) and (f) are quadratic equations; and model (d) is exponential.

In most of the previous studies, the correlation between the leaf area and the diameter at breast height was investigated (López-Serrano et al. 2000; Turner et al. 2000; Law et al. 2001; Adl 2007; Arias et al. 2007; Pokorný, Tomášková 2007; Calvo-Alvarado et al. 2008; Babaei-Kafaki et al. 2009), and less attention was devoted to the tree's crown-related parameters (Laubhann et al. 2010; Vyas et al. 2010). But, with the consideration of specific conditions of our investigated area, which is under traditional management, besides investigating other parameters, we also directed our attention to the crown-related parameters, particularly the crown volume. Our results indicate that the easily-measurable tree parameters such as DBH do not show a high correlation with leaf area. This point was also confirmed by some previous reports (Gower et al. 1999; Khan et al. 2005; Babaei-Kafaki et al. 2009). For instance, though Vyas et al. (2010) introduced a low $r^2$ in the relation between DBH and LA, estimated an excellent correlation between LA and the crown spread area. In another study on *Quercus macranthera* affected by traditional pollarding of the tree, Babaei-Kafaki et al. (2009) reported weak allometric equations between LAI, DBH and tree height ($r^2$ = 0.28 and 0.26, respectively). Since Armardeh forests can be considered as a traditional silvopastoral system, the moderate correlations of allometric equations found in this study could be explained in light of the fact that the branches had been pollarded for a period of 3 or 4 years; hence, the natural structure of the tree crown could be damaged. In fact, all branches of the old or young trees were only 3 or 4 years old. Branches and leaves do not have an opportunity for continuous and simultaneous growth along with the trunk of the tree growing both in diameter and height. Therefore, in any stage of the tree growth, branches remain very young. While

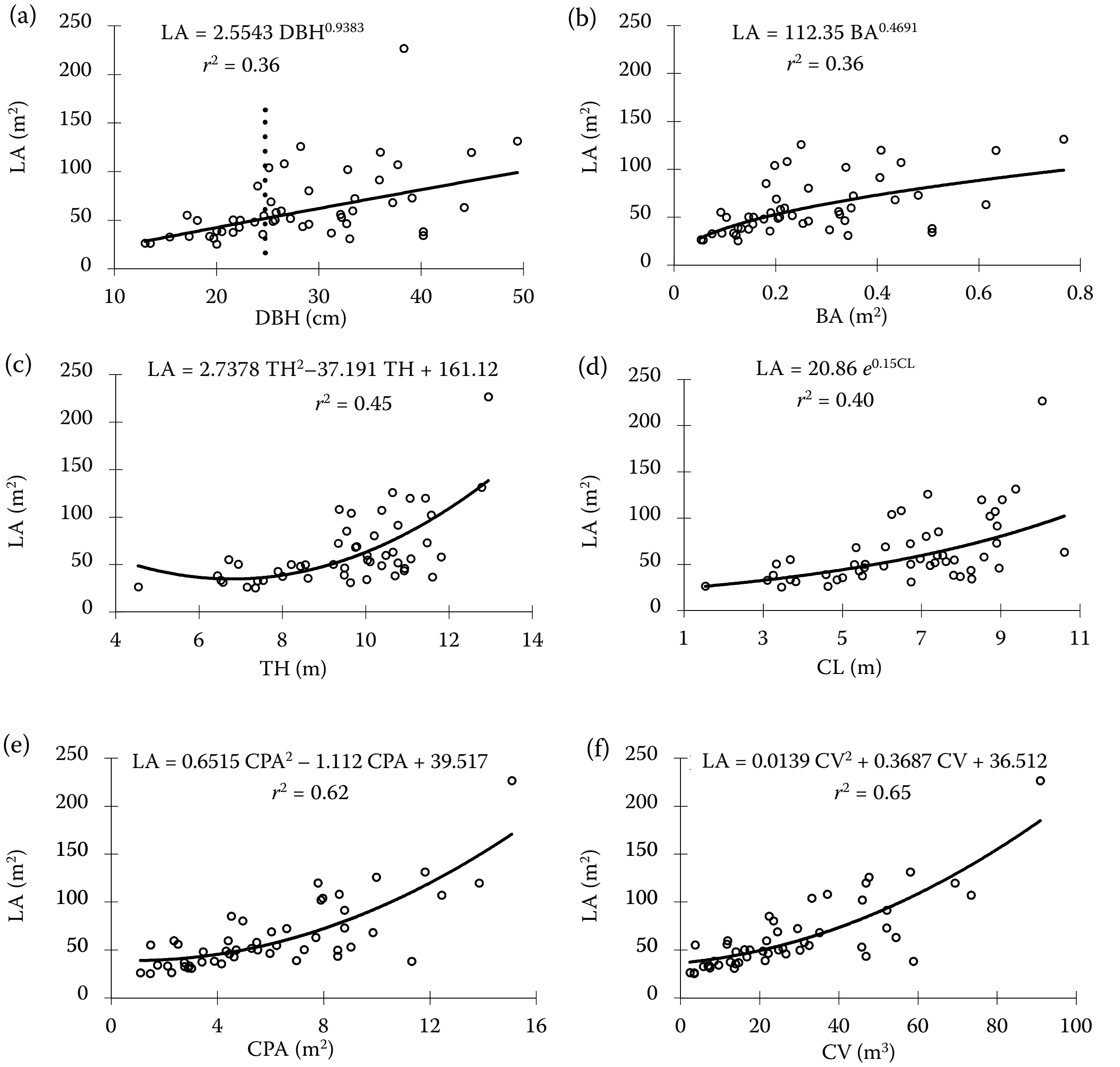


Fig. 2. Allometric relationships between leaf area (LA) and biophysical parameters such as diameter at breast height (DBH – a), basal area (BA – b), height of the tree (TH – c), crown length (CL – d), crown projected area (CPA – e), and crown volume (CV– f)

effects of traditional forest management have not been fully identified yet, it is evident that these practices have influenced the forest structure and tree characteristics (Valipour et al. 2009).

## CONCLUSION

The leaf area index (LAI) was estimated and the useful allometric equations for predicting the leaf area of Lebanon oak grown in Iran's Northern Zagros forests were also assessed. All regression models describing the relationship between leaf area and biophysical parameters were highly significant, however, the $r^2$ values were not very high ($r^2$ = 0.36–0.65). As compared with easily measurable variables such as DBH and basal area, related variables to the crown of trees such as crown projected area and crown volume had better capability to predict the leaf area at an individual tree level. The proposed allometric relationships in this research are most likely affected by pollarding of the tree. Therefore, the results of this study should be considered with caution, as the data correspond only to one stand within the range covered by the habitat of the pollarded oak. For this reason, further experiments, particularly those with the aim of making a comparison between LAI of trees in virgin, natural and disturbed forests of the study area, might be of significant scientific and practical interest.


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