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LAI and Leaf Biomass Allometric Equations for Three Common Tree Species in a Hyrcanian Temperate Forest

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Abstract

Despite the importance of Hyrcanian forests for biodiversity conservation, a few studies with biomass destruction has been done to predict biomass and carbon pools from this forest and there is a lack of knowledge in our country. Biomass and leaf area index (LAI) are important variables in many ecological and environmental applications and forest management. In this paper, allometric biomass and leaf area equations were developed for three common Hyrcanian tree species, Oriental Beech (*Fagus orientalis* Lipsky), Hornbeam (*Carpinus Betulus* Lipsky) and Chestnut-leaved Oak (*Quercus castaneifolia C. A. Mey*). To evaluate and estimate the leaf biomass and leaf area index of Oriental Beech, Horbeam and Chestnut-leaved Oak, 21, 27 and 17 individuals were selected and felled down, respectively. Tree characteristics such as diameter at breast height, total height, crown length and perpendicular diameters were measured. Destructive sampling was applied for determination of leaf biomass and LAI. Allometric equations were calculated for estimation of leaf biomass and LAI using simple linear regression and nonlinear regression analysis. The equations were compared based on several modelling parameters. Model comparison and selection were based on R^2, Akaike's information criterion (AIC), prediction error sums of squares, model standard error estimate (SEE), ΔAIC, and a correction factor. Based on the results, the mean values of leaf area, leaf biomass and LAI for Oriental Beech were 53.05 cm^2, 0.176 gr, 2.16, for Hornbeam were 27.2 cm^2, 0.128 gr, 1.13 and for Chestnut-leaved Oak were 62.419 cm^2, 0.401 gr, 2.26, respectively. The highest significant correlation for Oriental Beech was found between LAI and total height (R^2_{adj} = 0. 931), the highest significant correlation for Hornbeam was found between LAI and Dbh (R^2_{adj} = 0. 956) and the highest significance for Chestnut-leaved Oak was found between LAI and SqrtDbh (R^2_{adj} = 0. 956). Also, the best equations were obtained by means of an

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exponential regression model for Oriental Beech, the Log-transformed regression model for Hornbeam and of a transformed regression model for Chestnut-leaved Oak.

Keywords

Leaf Biomass, LAI, Hyrcanian Forests, Fagus Orientalis, Carpinus Betulus, Quercus Castaneifolia

1. Introduction

Physiologists and ecologists have long recognized the importance of both leaf surface area and foliar weight as factors affecting many trees and stand-level processes and functions such as photosynthesis, gas exchange, growth, stand productivity and canopy dynamics (Johansson, 2002; Karlik and McKay, 2002; Eriksson et al., 2005; Pourhashemi et al., 2012). The leaf area is the main surface of the exchange of energy and matter, between the plant canopy and the atmosphere, and therefore a key variable in driving the biological processes of the plants (Eriksson et al., 2005; Pourhashemi et al., 2012). By measuring the leaf area, it is possible to estimate parameters like canopy structure (Welles and Norman, 1991) and canopy productivity (Dantec et al., 2000). The leaf area index, or LAI, defined as half the total leaf area per unit ground surface area (Fournier et al., 2003; Menzies et al., 2006; kigomo et al., 2013) is an important canopy variable needed for many physiological and ecosystem studies (Menzies et al., 2006), is also a useful "bulk" parameter which is a necessary input parameter in many models. It has been related to canopy interception, transpiration, net photosynthesis and net primary productivity (Botkin, 1986; Pierce & Running, 1988; Gholz et al., 1991; Gower & Norman, 1991; Kigomo et al., 2013). LAI is related to atmospheric gas exchange that controls local carbon cycling. Leaf retention of gases such as CO_2 in the canopy is directly related to the amount of carbon released into the atmosphere (White et al., 1997; Menzies et al., 2006). LAI is also a key variable in analyzing energy absorption for photosynthesis (Cournac et al., 2002; Menzies et al., 2006), rates of photosynthesis, and for estimating primary and net primary production (Jensen, 2000; Menzies et al., 2006). Hyrcanian forests which are located in the north of Iran stretch up to an altitude of 2800 m above sea level. They are constituted of different forest stands with about 80 woody species. The communities of oriental beech (*Fagus orientalis* Lipsky) forests are the most important parts of the Hyrcanian forests due to their valuable ecological characteristics and their commercial value. Traditionally, measuring LAI was highly destructive because trees had to be felled for accurate measurements (Menzies et al., 2006).The aim of this work is to evaluate and estimate the leaf biomass and LAI of Oriental Beech and Chestnut-leaved Oak. So allometric leaf biomass and leaf area index equations were developed for Oriental Beech (*Fagus orientalis* Lipsky), Hornbeam (*Carpinus Betulus* Lipsky) and Chestnut-leaved Oak (*Quercu scastaneifolia* C. A. Mey).

2. Material and Methods

2.1. Study Area

The study was carried out in Chamestan Forest Districts (36˚22'00" - 36˚27'35"N and 52˚02'30" - 52˚07'30"E) located in northern forests of Iran (**Figure 1**). The study land has a total area of 2762 ha with altitudes which range between 250 and 1000 m a.s.l. The studied forests belong to the Beech community widely distributed in most parts of the district. The abundant tree species in the studied forests are *F. orientalis* L., *C. betulus* L. and *Q. scastaneifolia* C.A.M. According to data of the Nowshahr Meteorological Station, the mean annual precipitation and temperature of this area were 866 mm and 16.1˚C, respectively.

2.2. Sampling and Data Analysis

A total of 65 sample trees belonging to *F. orientalis* L. (21 individuals), *C. betulus* L. (27 individuals) and *Quercu scastaneifolia* C. A. Mey (17 individuals) were selected and felled down for leaf biomass and LAI estimation and allometric equation parameterization in the study area. All the trees were selected following lines of exploitation carried out by the forestry department of Nowshahr. The selection of each individual tree was based on diameter at breast height (1.3 m above the ground). The individuals were grouped into three DBH classes: 30

- 60, 60 - 80 and ≥80 cm, which is the diameter classification system commonly used in the Hyrcanian forests of Iran (Vahedi et al., 2013). Tree characteristics such as diameter at breast height, total height, crown length and perpendicular diameters were measured. Destructive sampling was applied for determination of leaf biomass and LAI. Gravimetric method was applied for calculating LAI (Adl, 2007). Allometric equations were calculated for estimation of leaf biomass and LAI using simple linear regression and nonlinear regression analysis. The equations were compared based on several modelling parameters. Model comparison and selection were based on R^2, Akaike's Information Criterion (AIC), prediction error sums of squares, model standard error estimate (SEE), ΔAIC, and correction factor (Sohrabi & Shirvani, 2012; Vahedi et al., 2013).

3. Results and Discussion

The mean values of DBH, height and crown area as measurable characteristics related to the subset of trees that was destructively sampled for leaf biomass and LAI estimation are summarized in **Table 1**. The diameter (DBH) range of the felled trees spanned from 17.19 to 108.5 cm so as to represent the diameter distribution reported in the studied stands. Based on the results, the mean values of leaf area, leaf biomass and LAI for Oriental Beech were 53.05 cm^2, 0.176 gr, 2.16, for Hornbeam were 27.2 cm^2, 0.128 gr, 1.13 and for Chestnut-leaved Oak were 62.419 cm^2, 0.401 gr, 2.26, respectively (**Table 1**).

Regression between the Leaf biomass (gr) and the Leaf Area (cm^2) of sampled trees are shown in **Figure 2**. A simple linear regression model using leaf biomass as independent variable showed significant correlation and produced R^2 of 0.931, 0.969 and 0.981 for Oriental Beech, Hornbeam and Chestnut-leaved Oak, respectively (**Figure 2**).

Univariate linear and non-linear regression models were developed using measured variables. Linear and non-linear regression analysis were parameterized to predict the values of LAI using a set of allometric parameters including DBH, height, crown area and their combinations of sampling trees of Oriental Beech, Hornbeam and Chestnut-leaved Oak (**Table 2** and **Table 3**).

Figure 1. Location of the study area.

Table 1. Sample trees and leaf characteristics of the oriental beech, hornbeam and chestnut-leaved Oak.

Species		Dbh (cm)	H (m)	Leaf Biomass (gr)	Mean Leaf Area (cm^2)	CA (m^2)	LAI
	Minimum	22.63	19.10	0.044	44.15	37.82	0.64
Oriental Beech	Maximum	108.50	34.85	0.355	66.66	120	3.66
	Mean	66.56	28.94	0.176	53.05	84.43	2.16
	Minimum	22.14	13.60	0.028	14.36	24.90	0.25
Hornbeam	Maximum	106.50	29.05	0.289	37.64	119.54	2.78
	Mean	58.59	22.57	0.128	27.20	82.46	1.13
	Minimum	17.19	16.27	0.139	42.20	25.86	0.58
Chestnut-leaved Oak	Maximum	72.85	29.83	0.867	88.05	99.30	4.27
	Mean	42.49	24.60	0.401	62.419	58.57	2.26

Table 2. Linear Regression and model description based on Dbh, height and crown area for the estimation of LAI of oriental beech, hornbeam and chestnut-leaved oak.

Species	Allometric model	R	$R^2_{(adj)}$	a	b	DW	CF	Std Error	RMSE	Sig
Oriental Beech	LAI = a(Dbh) + b	0.957	0.912	0.041	−0.548	1.190	-	0.30249	0.5500	***
	LAI = a(h) + b	0.951	0.900	0.203	−3.726	1.403	-	0.32272	0.5681	***
	LAI = a(CA) + b	0.898	0.798	0.046	−1.692	1.039	-	0.45901	0.6775	***
	LAI = a(Dbh × h) + b	0.958	0.914	0.001	0.136	1.247	-	0.29902	0.5468	***
	$LAI = a(Dbh \times h^2) + b$	0.952	0.903	2.95×10^{-5}	0.52	1.345	-	0.31897	0.5648	***
	$LAI = a((Dbh \times h)^2) + b$	0.909	0.820	2.19×10^{-7}	1.051	1.533	-	0.43337	0.6583	***
	$LAI = a(\sqrt{Dbh}) + b$	0.951	0.901	0.628	−2.871	1.258	-	0.32182	0.5673	***
	$LAI = a(\sqrt{h}) + b$	0.942	0.883	2.101	−9.098	1.464	-	0.34903	0.5908	***
	$LAI = a(\sqrt{Dbh \times h}) + b$	0.959	0.916	0.085	−1.527	1.237	-	0.29711	0.5451	***
	$LAI = a(\sqrt{Dbh \times h^2}) + b$	0.962	0.923	0.012	−0.787	1.213	-	0.28375	0.5327	***
	Ln(LAI) = a Ln(Dbh) + b	0.955	0.909	1.320	−4.810	1.097	1.0152	0.17384	0.4169	***
	Ln(LAI) = a Ln(h) + b	0.963	0.924	3.131	−9.861	1.173	1.0128	0.15957	0.3995	***
	Ln(LAI) = a Ln(Dbh × h) + b	0.959	0.917	0.931	−6.331	1.120	1.0140	0.16661	0.4082	***
	$Ln(LAI) = a\ Ln(Dbh \times h^2) + b$	0.961	0.920	0.719	−7.151	1.133	1.0135	0.16368	0.4046	***
	$Ln(LAI) = a\ Ln((Dbh \times h)^2) + b$	0.959	0.917	0.466	−6.331	1.120	1.0140	0.16661	0.4082	***
Hornbeam	LAI = a(Dbh) + b	0.910	0.823	0.027	−0.457	2.152	-	0.31266	0.5592	***
	LAI = a(h) + b	0.846	0.706	0.148	−2.217	1.974	-	0.40277	0.6346	***
	LAI = a(CA) + b	0.884	0.773	0.014	−0.020	2.468	-	0.35408	0.5950	***
	LAI = a(Dbh × h) + b	0.915	0.832	0.001	−0.041	2.223	-	0.30496	0.5522	***
	$LAI = a(Dbh \times h^2) + b$	0.919	0.840	2.69×10^{-5}	0.179	2.323	-	0.29715	0.5451	***
	$LAI = a((Dbh \times h)^2) + b$	0.923	0.847	2.48×10^{-7}	0.465	2.594	-	0.29031	0.5388	***
	$LAI = a(\sqrt{Dbh}) + b$	0.976	0.956	0.405	−1.899	2.060	-	0.15258	0.3853	***
	$LAI = a(\sqrt{h}) + b$	0.831	0.679	1.353	−5.269	1.944	-	0.42082	0.6487	***
	$LAI = a(\sqrt{Dbh \times h}) + b$	0.891	0.788	0.060	−1.030	2.066	-	0.34257	0.5853	***
	$LAI = a(\sqrt{Dbh \times h^2}) + b$	0.895	0.795	0.010	−0.576	2.092	-	0.33687	0.5804	***
	Ln(LAI) = a Ln(Dbh) + b	0.978	0.956	1.388	−5.605	2.110	1.0318	0.15009	0.3801	***
	Ln(LAI) = a Ln(h) + b	0.909	0.820	3.054	−9.548	1.806	1.0408	0.28278	0.5318	***
	Ln(LAI) = a Ln(Dbh × h) + b	0.925	0.851	0.959	−6.872	1.995	1.0335	0.25686	0.5068	***
	$Ln(LAI) = a\ Ln(Dbh \times h^2) + b$	0.922	0.846	0.732	−7.527	1.942	1.0348	0.26173	0.5116	***
	$Ln(LAI) = a\ Ln((Dbh \times h)^2) + b$	0.925	0.851	0.480	−6.872	1.995	1.0335	0.25686	0.5068	***
Chestnut-leaved Oak	LAI = a(Dbh) + b	0.975	0.948	0.058	−0.221	1.836	-	0.23267	0.4824	***
	LAI = a(h) + b	0.964	0.924	0.248	−3.837	2.843	-	0.28142	0.5305	***
	LAI = a(CA) + b	0.966	0.929	0.041	−0.135	2.172	-	0.27201	0.5215	***
	LAI = a(Dbh × h) + b	0.972	0.941	0.002	0.399	1.711	-	0.24708	0.4971	***

Continued

$LAI = a(Dbh \times h^2) + b$	0.966	0.930	5.18×10^{-5}	0.746	1.579	-	0.27043	0.5200	***
$LAI = a((Dbh \times h)^2) + b$	0.937	0.870	6.49×10^{-7}	1.260	1.486	-	0.36784	0.6065	***
$LAI = a(\sqrt{Dbh}) + b$	0.976	0.956	0.762	−2.609	2.403	-	0.21355	0.4621	***
$LAI = a(\sqrt{h}) + b$	0.957	0.910	2.382	−9.510	2.787	-	0.30636	0.5535	***
$LAI = a(\sqrt{Dbh \times h}) + b$	0.979	0.955	0.111	−1.306	2.430	-	0.21533	0.4640	***
$LAI = a(\sqrt{Dbh \times h^2}) + b$	0.978	0.954	0.018	−0.582	2.339	-	0.21863	0.4676	***
$Ln(LAI) = a\,Ln(Dbh) + b$	0.896	0.790	0.029	−0.557	1.586	1.0333	0.25604	0.5060	***
$Ln(LAI) = a\,Ln(h) + b$	0.962	0.921	0.136	−2.644	2.163	1.0124	0.15725	0.3965	***
$Ln(LAI) = a\,Ln(Dbh \times h) + b$	0.886	0.770	0.001	−0.237	1.557	1.0365	0.26782	0.5175	***
$Ln(LAI) = a\,Ln(Dbh \times h^2) + b$	0.869	0.739	2.55×10^{-5}	−0.054	1.531	1.0414	0.28499	0.5338	***
$Ln(LAI) = a\,Ln((Dbh \times h)^2) + b$	0.802	0.619	3.04×10^{-7}	0.224	1.539	1.0612	0.34463	0.5871	***

Table 3. Nonlinear regression and Model description based on DBH, height and crown area for the estimation of LAI of oriental beech, hornbeam and Chestnut-leaved Oak.

Species	X_{var}	Allometric Model	R	$R^2_{(adj)}$	a	b	CF	Std. Error	RMSE	F	Sig
Oriental Beech	Dbh	$LAI = alog(Dbh) + b$	0.930	0.859	2.274	−7.216	1.0765	0.384	0.6197	158.861	***
		$LAI = a(Dbh)^b$	0.955	0.909	1.320	0.008	1.0153	1.174	0.4171	261.509	***
		$LAI = aexp[a(Dbh)]$	0.942	0.883	0.023	0.417	1.0198	0.198	0.4450	196.767	***
	h	$LAI = a\log(h) + b$	0.931	0.862	5.367	−15.822	1.0745	0.379	0.6156	163.790	***
		$LAI = a(h)^b$	0.963	0.924	3.131	5.22×10^{-5}	1.0129	0.160	0.4000	315.045	***
		$LAI = a\exp[a(h)]$	0.966	0.931	0.117	0.064	1.0115	0.151	0.3886	352.636	***
	CA	$LAI = alog(CA) + b$	0.848	0.709	3.160	−11.754	1.1646	0.522	0.7430	64.211	***
		$LAI = a(CA)^b$	0.878	0.762	1.846	0.001	1.0406	0.282	0.5310	84.068	***
		$LAI = aexp[a(CA)]$	0.895	0.792	0.026	0.215	1.0352	0.263	0.5128	100.171	***
Hornbeam	Dbh	$LAI = alog(Dbh) + b$	0.864	0.738	1.440	−4.597	1.0749	0.380	0.6164	85.473	***
		$LAI = a(Dbh)^b$	0.929	0.859	1.388	0.004	1.0317	0.250	0.5000	183.917	***
		$LAI = aexp[a(Dbh)]$	0.918	0.838	0.024	0.219	1.0366	0.268	0.5177	156.202	***
	h	$LAI = alog(h) + b$	0.813	0.650	3.049	−8.316	1.1016	0.440	0.6633	56.598	***
		$LAI = a(h)^b$	0.909	0.820	3.054	7.14×10^{-5}	1.0409	0.283	0.5320	137.539	***
		$LAI = aexp[a(h)]$	0.919	0.839	0.144	0.035	1.0363	0.267	0.5167	157.306	***
	CA	$LAI = alog(CA) + b$	0.836	0.668	1.020	−3.196	1.0899	0.415	0.6442	67.107	***
		$LAI = a(CA)^b$	0.893	0.790	0.015	0.977	1.0476	0.305	0.5523	113.763	***
		$LAI = aexp[a(CA)]$	0.876	0.760	0.012	0.331	1.0546	0.326	0.5710	96.039	***
Chestnut-leaved Oak	Dbh	$LAI = alog(Dbh) + b$	0.975	0.947	2.377	−6.460	1.0278	0.234	0.4837	288.591	***
		$LAI = a(Dbh)^b$	0.950	0.896	1.269	0.019	1.0163	0.180	0.4243	139.439	***
		$LAI = aexp[a(Dbh)]$	0.896	0.790	0.029	0.573	1.0333	0.256	0.506	61.031	***
	h	$LAI = alog(h) + b$	0.948	0.891	5.662	−15.794	1.0581	0.336	0.5797	132.074	***
		$LAI = a(h)^b$	0.971	0.939	3.179	7.92×10^{-5}	1.0096	0.138	0.3715	247.238	***
		$LAI = aexp[a(h)]$	0.962	0.921	0.136	0.071	1.0124	0.157	0.3962	186.564	***
	CA	$LAI = alog(CA) + b$	0.963	0.922	2.270	−6.782	1.0412	0.284	0.5329	190.223	***
		$LAI = a(CA)^b$	0.927	0.849	1.197	0.017	1.0238	0.217	0.4658	91.014	***
		$LAI = aexp[a(CA)]$	0.886	0.771	0.021	0.600	1.0363	0.267	0.5167	54.773	***

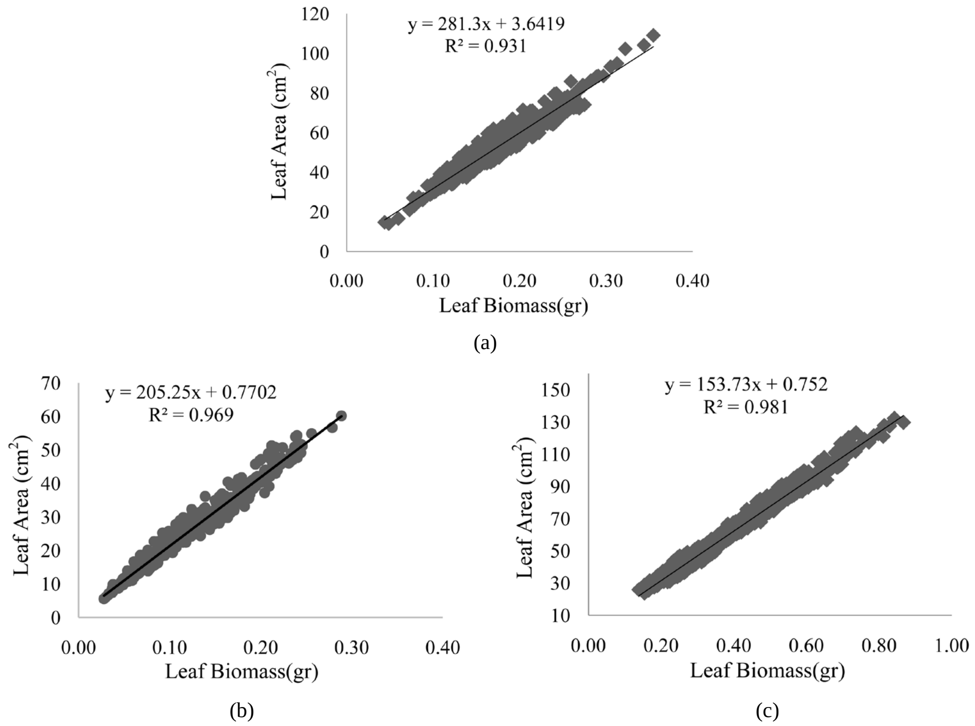

Figure 2. Regression between the leaf biomass (gr) and the Leaf Area (cm^2) of: (a) Oriental Beech; (b) Hornbeam and (c) Chestnut-leaved Oak.

The best-fit equations had adjusted R^2 values between 0.709 to 0.931 and RMSE values between 0.7430 and 0.3886 for Oriental Beech, R^2 values between 0.650 to 0.956 and RMSE values between 0.6633 and 0.3801 for Hornbeam and R^2 values between 0.619 to 0.956 and RMSE values between 0.5871 and 0.4621 for Chestnut-leaved Oak (**Table 1** and **Table 2**).

Allometric equations for estimating LAI from DBH and height and their combinations were derived. Based on results the highest significant correlation for Oriental Beech was found between LAI and total height (R^2_{adj} = 0. 931), the highest significant correlation for Hornbeam was found between LAI and Dbh (R^2_{adj} = 0. 956) and the highest significance for Chestnut-leaved Oak was found between LAI and SqrtDbh (R^2_{adj} = 0. 956). Also, the best equations were obtained by means of an exponential regression model for Oriental Beech, the Log-transformed regression model for Hornbeam and of a transformed regression model for Chestnut-leaved Oak.

4. Conclusions

In the presence of complex environmental gradients, allometric equations can provide additional information to improve the knowledge of LAI distribution.

Allometric equations presented in this study associated with oriental beech, Hornbeam and Chestnut-leaved oak, the three common species in the Hyrcanian forests, may bring additional information for the LAI patterns and distribution. The allometric equations provide improved methods for predicting LAI, leaf biomass and also carbon storage in Hyrcanian forests from standard forestry measurements, which means these equations may be applied to historical and new forest data.

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