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Investigating the Crown Structure and Carbon Storage of Beech Trees (*Fagus orientalis* L.) in an Unmanaged-Temperate Hyrcanian Region (Case Study: Alandan Forest, Mazandaran)

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ABSTRACT

Aims: Assessing tree crown traits are important in the forests that can be considered for silvicultural opeRations. The primary purpose of this study was to investigate tree crown features and Carbon storage value of Oriental beech (*Fagus orientalis* L.) and to determine the correlations among these variables in an unmanaged and temperate forest in the Hyrcanain region, northern Iran.

Materials & Methods: Data were collected randomly from 90 one-stemmed and healthy beech trees in overstorey and unlogged forests in the Hyrcanian Region, and tree dimensions, including crown Length, crown Width, bole, DBH, and height, were measured.

Findings: The study revealed significant differences between crown tree traits and Carbon storage regarding height and DBH classes. The higher value of Carbon storage (kg) was observed in the height class of more than 40m (2619.82±196.15) and DBH class of more than 60cm (2670.48±126.15). Correlation analysis indicated that some tree traits correlated significantly with crown Productivity, Length, Width, and Ratio for beech trees ($P< 0.05$, $P< 0.01$). There was a strong positive correlation between Carbon storage and most beech tree traits in the research site ($p < 0.01$).

Conclusion: In general, the main tree crown size disparities and significant interactions among features of beech trees in unlogged forests suggest the ability of these trees to modify the morphological traits within the stand. It is essential to consider crown sizes of beech trees in future forest management planning in the Hyrcanian temperate region.

Keywords: Broad-Leaved; Crown Size; Deciduous Tree; Unlogged Forest.

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Introduction

Individual tree crowns are the fundamental part of the forest canopy structure, making forests the major territorial ecosystems on Earth and offering a variety of ecological facilities [1]. In forests, interactions influence the size and placement of individual tree crowns in the canopy, shaping the plant community's structure [2]. Under specific environmental conditions, forest trees are thought to grow primarily in response to their age, stem and crown dimension, and competitive position within the stand [3]. Forest stand structure defines many properties of the stand and individual trees within the stand, and the distribution of crown dimensions is an essential factor in canopy structure [4]. The tree crown exerts a vital role in the Productivity of trees as it is the site of the physiological processes that lead to tree growth and development, primarily photosynthesis, respiRation, and transpiRation [5]. For biomass production, tree crown has fundamental physiological tasks and play an important role in tree endurance, quality, and steadiness [6]. The shape and distribution of the canopy regulate its vertical and horizontal arrangement, a major characteristic for understanding growth and competition processes in forests [7]. Tree crown traits relate to several stand parameters, including species, age, location, species composition, competition, and management systems based on Štefancik [8]. Seidel et al. (2015) showed that tree crowns' horizontal expansion is generally reflected in tree growth [9]. Juchheim et al. (2017) found lesser horizontal maximum crown height and greater crown area with rising management intensity for beech trees [10]. Abrari Vajari (2018) showed that in a mixed beech forest, there is a positive relationship between the competition Index and crown Ratio and height-diameter Ratio for oriental beech trees [11]. Pretzsch et al. (2022) have shown that the external features of the tree's crown are functionally associated with the internal structure of the trunk [12]. Tree crown structure is becoming progressively essential for knowing tree structure and dynamics of forests [26]. Forest ecosystems are essential in the universal Carbon cycle as forest stores and contribute to climate change mitigation [13]. Forests stock nearly 862 Gt of Carbon in living and dead plants and soil, 42% of which is stocked in living biomass [14]. Carbon cycling has recently developed into a major global problem, and plants have played an important role in Carbon stock [15]. Tree species impact ecosystem Carbon stock through biomass and trends in Carbon gathering the tree's life, resulting in different maximum biomass stock and species effects on soil Carbon value [16]. Above-ground biomass of trees is a tool for assessing Carbon contents [17], and tree species affect the Carbon stock of living biomass due to the different characteristics of trees [18]. Trees denote one of the main Carbon stock parts in forest ecosystems, and thus research designed for assessing tree biomass has gradually increased [19]. Deciduous broad-leaved forests in the temperate Hyrcanian Region in northern Iran are notable for their diversity of community types, providing us with a way to study tree traits. Different forest types vary in their tree structure and composition. The shade-tolerant Oriental beech (*Fagus orientalis* L.) trees are considered ecologically and economically important in forest ecosystems. Characterizing beech tree crowns is significant for understanding tree morphology, forest ecosystem dynamics, and its use in forest management in the Hyrcanian Region. Also, there is a limited amount of research on the above-ground Carbon storage of beech trees that might be used to assess the Carbon storage potential of the forest ecosystem in Iran. In this study, we aimed to analyze the crown structure traits and above-ground Carbon storage for oriental beech trees in forest ecosystems. Hence, our study addressed the hypotheses that: (1) Height and DBH of beech trees affect the crown size and above-ground Carbon storage; (2) Crown structure and above-ground Carbon storage significantly correlated to some features of beech trees; and (3) K/d Ratio changes in different height and DBH classes, also correlated to some features of beech trees.

Materials & Methods

The study area is located in an uneven-aged and broadleaved forest in the Hyrcanian Region, northern Iran (36° 12′ N, 53° 24′ E), comprising an area of about 37 ha (Figure1). This forest stand is positioned at an elevation of 1350–1650 m above sea level, with a slope of 0–60% and northwest-oriented. A typical humid climate prevails in this study, with a mean annual precipitation of 858 mm and a mean annual temperature of 10.5 ˚C [20]. The dominant soil types are pseudogleyic and gley [20]. The Deciduous-broadleaved Oriental beech trees are present in all three layers, from overtopped to dominant ones, and form the dominant forest type. Other tree species, including alder (*Alnus subcordata* C.A. Mey), hornbeam (*Carpinus betulus* L.), and maple (*Acer velutinum* Boiss.), were detected in the stand. This tree's number and volume within the stand are 228/ha [97.4%] and 497m^3/ha [96.7], respectively. Oriental beech, as a woody plant, is one of the primary forest species in the Hyrcanian temperate forests of northern Iran, usually covering mesic sites and growing in mixed stands. In addition to its distribution and stand area, it plays a vital role in great ecological and economic values. The studied beech stands from structurally multi-layered and all-aged and established from natural reproduction. The beech tree structure traits are presented in Table 1.

Field Measurements

In the summer of 2022, 90 one-stemmed and healthy oriental beech trees (Figure 1) in overstorey were randomly measured in an uneven-aged and unlogged forest stand. The minimum distance among trees was 20 m (*r* = 20 m). For the selected target beech tree (diameter at breast height≥20cm), some variables, including total height, diameter at breast height (DBH), crown Length (CL), height/diameter Ratio(HD), crown Ra-

Figure 1) An uneven-aged Oriental beech (*Fagus orientalis* L.) stands in the Hyrcanian Region (Alandan forest, Mazandran Province), Iran.

tio (height/crown Length, CR), crown surface area (CSA), crown volume (CV), pruning Index (crown Length/bole height Ratio) and crown Productivity (CSA/CV) were surveyed (Table 1). All trees' total height and DBH were measured using a Suunto clinometer and diameter tape, respectively. The crown surface area (CSA) and the crown volume (CV) were expressed by Promis et al. [21]. The crown radius was measured as the distance from the center of the tree's trunk to its crown's perimeter using the vertical sighting method [22]. The mean value of radii in different aspects (N, E, S, and W) was applied to the crown radius of beech trees. The $r_{ain}/_{max}$ Ratio (crown roundness) is calculated by dividing the longest to shortest of the four crown radii. After measuring height and diameter at breast height for trees, these parameters were classified.

Tree Carbon Measurement

To measure the above-ground tree Carbon, the volume of standing beech trees was measured using the volume equation (V= H×D2×0.5×) developed by Zobeiry [23]. Above-ground tree biomass (AGTB) was calculated applying the following formula: AGTB = Vol × wood density; then, for converting AGBT to tree Carbon, a Carbon-Ratio factor of 0.47 was used [24].

Statistical Analyses

The data sets we abstract analyzed for normality distribution using a Kolmogorov-Smirnov test. Before statistical analysis,

Table 1) Descriptive statistics for beech tree traits (n=90).

Variable	Mean	Std. Deviation	Minimum	Maximum
Crown Productivity ($m^2.m^{-3}$)	0.097	0.036	0.058	0.303
Height(m)	39.38	4.61	25.70	48.30
DBH(cm)	0.616	0.182	28.5	100.15
Crown Length (m)	22.32	5.45	6.60	24.35
Crown Width (m)	6.68	2.24	2.95	14.80
H/D Ratio	67.24	14.03	40.73	100
Crown Ratio	1.87	0.519	1.15	4.37
Bole (m)	17.05	5.32	5.2	27.3
Pruning Index	1.58	1.06	0.29	6.44
K/d (crown diameter/crown diameter)	11.28	3.84	5.09	26.85
r_{min}/r_{max} (crown roundness)	0.49	0.16	0.16	0.76

Table 2) Means of crown size (±SEM) for beech trees in different DBH classes (Independent Test).

Variable		DBH Class		Sig.
< 60cm(n=45)		> 60cm(n=45)		
Crown Length (m)	22.41±0.78	23.15±0.68	0.482	
Crown Width (m)		5.66±0.26	7.53±0.33	0.000
Crown Ratio		1.70±0.05	1.87±0.05	0.025
Crown Productivity ($m^2.m^{-3}$)		0.12±0.007	0.08±0.002	0.046

Table 3) Means of crown size (±SEM) for beech trees in different height classes (Independent t-Test).

Variable	Height Class		Sig.
	< 40m(n=43)	> 40m(n=47)	
Crown Length (m)	21.18±0.82	23.63±0.75	0.033
Crown Width (m)	6.0±0.25	7.46±0.38	0.002
Crown Ratio	1.17±0.04	1.90±0.5	0.015
Crown Productivity ($m^2.m^{-3}$)	0.11±0.007	0.08±0.002	0.027

Table 4) Pearson's correlation coefficients among crown structure and some features of beech trees in the research site.

Variables	Crown Productivity		Crown Length		Crown Width		Crown Ratio	
Height	r= -0.494**	P=0.000	r= 0.451**	P=0.000	r= 0.355 **	P=0.001	r= -0.131	P=0.219
DBH	r= -0.304**	P=0.004	r= 0.366**	P=0.001	r= 0.533**	P=0.000	r= -0.061	P=0.567
H/D	r= 0.119	P=0.267	r= -0.146	P=0.171	r= -0.480**	P=0.000	r= -0.037	P=0.733
Pruning Index	r= -0.532**	P=0.000	r= 0.763**	P=0.000	r= -0.103	P=0.336	r= -0.694**	P=0.000
Bole	r= 0.450**	P=0.000	r= -0.634**	P=0.000	r= 0.137	P=0.199	r=0.758**	P=0.000
r_{min}/r_{max}	r= -0.005	P=0.962	r= 0.047	P=0.659	r= 0.475**	P=0.000	r= 0.026	P=0.810

**$p < 0.01$

Table 5) Means of K/d Ratio values (±SEM) for beech trees in DBH and height classes (Independent t-Test).

Variable	DBH Class		Height Class	
	< 60cm(n=45)	**> 60cm(n=45)**	**< 40m(n=43)**	**> 40m(n=47)**
K/d	12.54±0.68	10.14±0.41	12.34±0.62	10.27±0.42

all data were tested for the equality of variances using the Levene test. An independent t-Test was used to examine the crown size, K/d Ratio, and Carbon storage variations in different DBH and height classes for beech trees. The relationships among crown size, K/d Ratio, and Carbon storage with tree traits were tested using the Pearson correlation coefficients. All significant differences were considered at P<0.05 and P<0.01. All statistical analyses were performed using the package SPSS, version 24.

Findings

The mean values of CL and CR of beech trees were higher in the DBH class above 60cm, but a higher value of CP was observed in the DBH class below 60cm ($P< 0.05$, $P< 0.01$; Table 2). The crown structure of beech trees showed a significant difference between

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height classes ($p < 0.05$ $P< 0.01$; Table 3). Correlation analysis showed that some tree traits correlated significantly with the CP, CL, CW, and CR for beech trees ($P< 0.05$, $P< 0.01$; Table 4). The K/d Ratio values were higher in DBH< 60cm and height< 40m for beech trees in forest stands ($p < 0.01$; Table 5). Results of correlation analysis (Table 6) showed that the K/d Ratio was positively correlated with CW, H/D Ratio, and $_{min}/_{max}$ values ($p < 0.01$, $p < 0.05$) but negatively with H, DBH, bole ($p < 0.01$, $p < 0.05$). However, the relationship between the K/d Ratio and CL, crown Ratio, pruning Index, and crown Productivity was insignificant ($p > 0.05$). The highest values of Carbon storage of beech trees were observed in DBH> 60cm and height> 40m ($p < 0.01$; Table 7). There was a strong positive correlation between the Carbon storage and most beech tree traits in the research site ($p < 0.01$), but Carbon storage was negatively significantly correlated with crown Productivity ($p < 0.01$; Table 8).

Discussion

According to results (Table 2 and 3) in the mature oriental beech forests, the broader and thicker crowns of trees can be attributed to absorbing the greater light, based on Yang et al. [25]. The greater crown Productivity of beech trees can be indicated by a higher capacity for growth, as noted by Xu et al. [26]. Based on Fichtner et al. [27], the central tree crown structure variations and significant relationships (Table 4) among dimensions of beech trees in unlogged forests indicate the capability of these trees to change their morphological traits. Although, some morpho-

Table 6) Pearson correlation coefficient between K/d Ratio and tree traits.

Variables	K/d Ratio	
	r	*P*
Height(m)	-0.043**	0.000
DBH(cm)	-0.389**	0.000
Bole(m)	-0.225*	0.033
Crown Length	-0.144	0.174
Crown Width	0.518**	0.000
H/D Ratio	0.349**	0.001
Crown Ratio	-0.119	0.265
Pruning Index	0.009	0.937
Crown Productivity ($m^2.m^{-3}$)	0.049	0.645
r_{min}/r_{max}	0.254*	0.016

Corresponding values were significant at ** 0.01 level and * 0.05 level.

Table 7) Carbon storages for beech trees in different DBH and height classes (mean±SEM).

Variable	DBH Class		Height Class	
	< 60cm	> 60cm	< 40m	> 40m
Carbon Storage (Kg)	910.72±47.92	2670.48±126.15	1113.81±105.5	2619.82±196.15

Independent t-Test.

Table 8) Correlation between Carbon storage and morphological traits of beech trees.

Variables	Carbon Storage	
	r	*P*
Height	0.735**	0.000
DBH	0.969**	0.000
Crown Length	0.373**	0.000
Crown Width	0.531**	0.000
H/D Ratio	-0.794**	0.000
Crown Surface Area	0.522**	0.000
Crown Volume	0.631**	0.000
Crown Ratio	-0.091ns	0.395
Pruning Index	-0.072ns	0.502
Crown Productivity	-0.326**	0.002

**$p < 0.01$, ns: no significant.

logical traits measured in the field were not correlated with each other. A significant relationship between DBH and crown dimensions was reported by many researchers [8]. Furthermore, the changes in crown dimensions of beech trees could be related to the distance from neighbor trees, as mentioned by Seidel et al. [9]. A strong correlation was observed between crown size and some features of beech trees which can be associated with different tree strata in beech forests (Table 4). According to Aakala et al. [28], the increase in crown size in taller and thicker trees can be attributed to the absorption of more light and the reduction of competition. Our study revealed that variability in beech tree dimensions and the amount of small live trees modify the K/d Ratio (Tables 5, 6). Hemery et al. [29] found that the K/d Ratio for beech trees decreased with increased stem diameter. Delagrange et al. [30] declared that crown morphology traits are influenced by light and plant size. The research results showed that taller beech trees (Table 7) and trees with a large diameter in the forest have an influential role in the production of biomass and Carbon storage, as well as the forest dynamics. Big-sized trees in the forest have the most significant impact on the Carbon storage of trees, and it has been declared in many types of research [24]. Therefore, the disparity in tree size regarding DBH and tree height may be determined by the research site's above-ground Carbon storage differences among beech trees. Research findings in West African ecosystems showed that trees with a large diameter, compared to smaller-sized classes, have a more significant biomass Carbon [31]. Also, the significant correlation between Carbon storage and the structural characteristics of beech trees shows that these characteristics are important factors that influence their Carbon storage (Table 8). A positive correlation between the height and canopy of trees with their Carbon storage has been reported in several studies [32]. The increase in Carbon storage with increasing tree diameter emphasizes the significance of conserving mature -old large beech trees to maintain this Carbon deposited in the forest ecosystem, as noted by Mildrexler et al. [14]. The interactions between beech tree structure and above-ground Carbon storage in our research might help evaluate climate change's influences in the Hyrcanian Region.

Conclusions

Accurate tree crown traits and above-ground Carbon storage assessment are essential for forest management. Our findings showed that height and DBH differences of beech trees play an essential role in the variability of tree traits and Carbon storage. This study revealed the interactions among structural traits of beech trees in uneven-aged and multi-layer forests of the Hyrcanian Region. Generally, we suggest forest managers consider their silvicultural opeRations on 1) assessing tree crown traits and 2) protecting several high-quality and large-sized trees that provide high above-ground biomass in the forest.

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Conflict of Interest: The corresponding author has no conflict of interest.

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