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Biomass Carbon and Nitrogen Content of Hardwoods in Novi Pazar (Serbia)

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Abstract. **To investigate and compare hardwood species based on their carbon (C) and nitrogen (N) storage capacity, a study of the C and N content of the bark and wood of nine common hardwood broadleaves in Novi Pazar, southwestern Serbia, was conducted. Compared with sycamore maple, Norway maple, common ash, common hornbeam, black locust, European beech, Turkey oak, and sessile oak, field maple has the highest C/N ratio in wood (37.05 ± 3.23), representing the best hardwood species for biomass production.**

Hardwoods grow more slowly than softwood trees, which results in the timber harvested from them being more dense, heavy, and hard-wearing. Besides being ornamental trees, they are used for construction, flooring, furniture making, and other purposes, such as biomass production. In Serbia, hardwoods make up 79% of forest resources, from which the vast majority of biomass is produced (98%) (State Enterprize "Srbijašume" 2024).

The biomass element that determines the energy released during oxidation is C. The biomass C content may vary depending on many factors, including species. The organically bound N content is also important because it is related to NOx emissions that result after combustion (Hadrović et al. 2021, 2022).

The biomass C and N content of hardwood broadleaves has remained insufficiently investigated, although it was studied by others (e.g., Filippou et al. 2018). Our study aimed to compare nine common hardwood species in the forest area of Novi Pazar, southwestern Serbia, and to select the best hardwoods for biomass production based on their C and N storage capacity. These species make up 96.71% of hardwood forests in the area (Bureau for Planning and Design in Forestry 2018).

Materials and Methods

Biomass samples (branches 10–20 cm long, >7 cm thick) of nine hardwood broadleaves were collected at 13 geographic points in Novi Pazar, southwestern Serbia: 1) sessile oak [*Quercus petraea* (Matt.) Liebl.] (lat. 43.13296°N, long. 20.57776°E), 2) Turkey oak (*Quercus cerris* L.) (lat. 43.13241°N, long. 20.5806°E; lat. 43.18152°N, long. 20.37785°E), 3) European beech (*Fagus sylvatica* L.) (lat. 43.11516°N, long. 20.59585°E; lat. 43.16261°N, long. 20.38278°E), 4) common ash (*Fraxinus excelsior* L.) (lat. 43.11509°N, long. 20.6002°E), 5) sycamore maple (*Acer pseudoplatanus* L.) (lat. 43.0664°N, long. 20.59239°E), 6) Norway maple (*Acer platanoides* L.) (lat. 43.05571°N, long. 20.57673°E), 7) field maple (*Acer campestre* L.) (lat. 43.11693°N, long. 20.5967°E; lat. 43.1441°N, long. 20.37809°E), 8) common hornbeam (*Carpinus betulus* L.) (lat. 43.12976°N, long. 20.58175°E; lat. 43.16233°N, long. 20.39197°E), 9) black locust (*Robinia pseudoacacia* L.) (lat. 43.12709°N, long. 20.57662°E). Sample plots were established in similar environmental and forest stand conditions (Bureau for Planning and Design in Forestry 2018) to enable comparison between the species. Each species was represented by one or two sample plots, five individuals, and a sample per individual (total of 45 samples). The bark and core of the samples were analyzed independently.

All samples were oven-dried to constant weight, at 105 °C, and ground in a mill. Sample weights of 30 mg were separated for C and N determination in a CHN analyzer (CHN analyzer Vario EL III; Elementar, Hanau, Germany) according to standard procedure (AOAC International 2006).

The obtained data were used to calculate mean values of all variables and to determine standard deviation for each mean. The significance of differences between the means was determined by analysis of variance (ANOVA) with the post hoc Fisher's least significant difference test. A canonical discriminant analysis (CDA) was conducted to extract a set of linear combinations of variables that best reveal the differences among the analyzed species. Differences among the compared groups were defined by squared Euclidean distances used in the cluster analysis. All statistical analyses were performed using statistical software (Statgraphics ver. XVI.I.; Statpoint Technologies, Inc., Warrenton, VA, USA).

Results and Discussion

All species studied, excluding sessile oak, had a greater N content and lesser C/N ratio in bark than in wood; in most species (except in European beech, common ash, and sycamore maple), the C content was greater in wood than in bark (Table 1) similar to the results of the investigations of fruit and softwood broadleaved species in southwestern Serbia (Hadrović et al. 2021, 2022). In contrast, in the research of conifer species in the same area (Hadrović et al. 2019), the N content was mostly low and the C content was mostly high in bark compared with wood.

ANOVA revealed significant differences ($P < 0.05$) between the means of N content and C/N ratios in bark and wood, forming four homogeneous groups in most cases. Comparing the means, the lowest N content and the highest C/N ratio in bark were found in sycamore maple, and the highest N content and the lowest C/N ratio in field maple. In wood, the lowest N content and the highest C/N ratio were determined for field maple, and the highest N content and the lowest C/N ratio for sessile oak (Table 1). Literature data for the C and N content of hardwoods predominantly refers to trunk or mixed tree parts, whereas relevant data for branches and twigs is limited. The C content is usually lower in branches compared with trunks (Thomas and Martin 2012), and the opposite is true for the N content (Zhao et al. 2019). In comparison with available literature data, the obtained mean value of C content in the bark and wood of European beech was less than that given by Filippou et al. (2018). The obtained C values for all analyzed species were also less than those reported in ISO 17225–1 for broadleaved species (Institute for Standardization of Serbia 2021). On the other hand, the N content in the bark and wood of European beech was greater than that stated by Filippou et al. (2018). The N values of the analyzed species were also greater than the typical values in ISO 17225–1 (Institute for Standardization of Serbia 2021). Still, comparing the results with those obtained for conifer, fruit, and softwood broadleaved species in southwestern Serbia (Hadrović et al. 2019, 2021, 2022), the C content in the bark of the analyzed species was generally greater than the content determined in the bark of fruit species, and the N content was less in these species than in the softwoods. Also, in wood, the C content was mostly greater in the analyzed species than in the conifers, and the N content was mostly less in these species than in the conifers and fruits, which makes them better candidates for biomass production than conifers, but less suitable than fruits and softwoods. The critical N amount in biomass is 1% to 2%, and it can be affected by removing bark, which in hardwoods participates with 8% to 12% (Dauber and Zenke 1978).

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Table 1. Descriptive, univariate and multivariate statistics on carbon (C) and nitrogen (N) contents and their ratios (C/N) in the bark and wood of nine hardwood broadleaves in Novi Pazar, southwestern Serbia.

	Quercus petraea	*Quercus cerris*	*Fagus sylvatica*	*Fraxinus excelsior*	*Acer pseudoplatanus*	*Acer platanoides*	*Acer campestre*	*Carpinus betulus*	*Robinia pseudoacacia*	CDA		ANOVA	
										CDA1	CDA2	F-ratio	*P* value
Cluster	1	1	2	2	4	2	3	2	1				
Eigenvalue	—	—	—	—	—	—	—	—	—	5.42	2.05	—	—
Percentage	—	—	—	—	—	—	—	—	—	67.34	25.42	—	—
Bark													
N(%)	1.65 ± 0.11 cd[i]	1.49 ± 0.10 cd	2.11 ± 0.13 b	1.68 ± 0.15 cd	1.40 ± 0.16 d	2.10 ± 0.19 b	2.59 ± 0.72 a	1.76 ± 0.20 bc	1.54 ± 0.11 cd	0.54	0.30	9.89	**0.0000**
C(%)	39.34 ± 3.08 ab	37.39 ± 3.11 b	42.40 ± 3.03 a	42.26 ± 2.90 a	40.24 ± 2.88 ab	42.97 ± 2.87 a	40.64 ± 3.00 ab	40.91 ± 3.02 ab	37.69 ± 2.93 b	−0.09	0.23	2.09	0.0628
C/N	23.90 ± 3.10 bc	26.95 ± 3.21 ab	20.05 ± 2.85 cd	25.20 ± 3.16 ab	28.70 ± 2.92 a	20.40 ± 3.01 cd	18.10 ± 4.50 d	23.30 ± 2.99 bc	24.60 ± 3.14 ab	0.10	**−0.83**[ii]	5.58	**0.0001**
Wood													
N(%)	1.72 ± 0.10 a	1.46 ± 0.14 b	1.25 ± 0.14 cd	1.42 ± 0.17 bc	1.11 ± 0.16 d	1.27 ± 0.17 cd	1.14 ± 0.15 d	1.36 ± 0.09 bc	1.52 ± 0.12 b	**−0.66**	0.49	9.27	**0.0000**
C(%)	41.10 ± 2.84 a	41.33 ± 2.88 a	40.88 ± 2.89 a	41.02 ± 2.75 a	39.95 ± 2.89 a	42.99 ± 2.91 a	42.01 ± 3.09 a	42.02 ± 3.03 a	41.67 ± 3.13 a	−0.09	0.22	0.43	0.8946
C/N	23.90 ± 2.94 e	28.80 ± 2.93 d	32.75 ± 2.84 bc	28.80 ± 2.96 d	36.10 ± 3.06 ab	33.90 ± 3.09 abc	37.05 ± 3.23 a	31.05 ± 3.04 cd	27.40 ± 2.73 de	**0.64**	−0.13	10.33	**0.0000**

[i] Mean ± *SD*. Means within a row not followed by the same letter(s) are significantly different at $P < 0.05$.

[ii] Bold values denote variables with discriminant function coefficients >0.60 for canonical discriminant analysis (CDA), and $P < 0.05$ for analysis of variance (ANOVA).

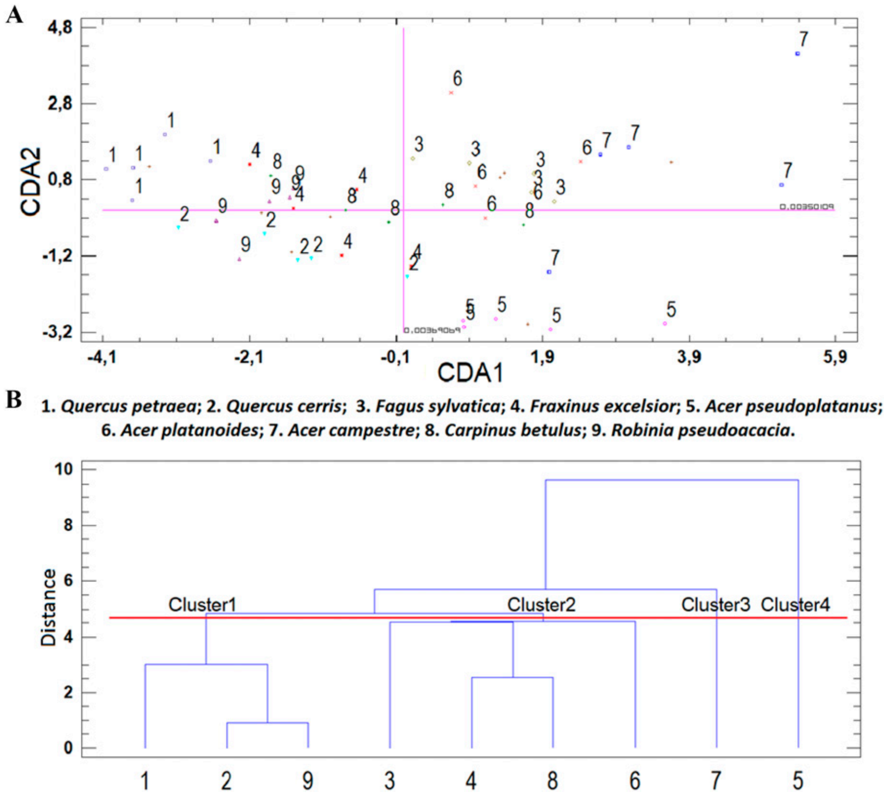

Fig. 1. (**A**) Canonical discriminant analysis (CDA) scatterplot, and (**B**) dendrogram of nine hardwood broadleaves based on the carbon and nitrogen content in their bark and wood.

In the CDA, the first function accounted for 67.34% of the discrimination and the second one discriminated another 25.42%. The N content and C/N ratio, with discriminant function coefficients >0.60, are responsible for the differentiation along both axes, which resulted in the differentiation of species. Similar to the results of ANOVA, four groups of species were formed (Fig. 1A). Cluster analysis identified the same groups (Table 1, Fig. 1B), indicating that significant differences exist among these groups of species in terms of N and C storage capacity, which should be considered an important factor in using hardwoods for biomass production.

Based on the obtained results, it can be concluded that field maple has the highest C/N ratio in wood compared with sycamore maple, Norway maple, common ash, common hornbeam, black locust, European beech, Turkey oak, and sessile oak, representing the best hardwood species for biomass production.

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