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Biomass Carbon and Nitrogen Content of Softwood Broadleaves in Southwestern Serbia

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Abstract. **To select softwood broadleaves for biomass cropping, a study of the carbon and nitrogen content of the bark and wood of six softwood broadleaves in southwestern Serbia was conducted. Compared with white willow, european aspen, common alder, black poplar, and silver birch, goat willow has a high potential for carbon storage in bark and wood, representing a promising softwood broadleaf for biomass production.**

Besides being ornamental trees, softwood broadleaves are used for timber and paper production. They are also a good source of renewable energy. Their ability to fix atmospheric nitrogen (N) (Pernar et al., 2012) allows for large biomass production, making the production in short rotation sustainable.

The biomass element that determines the energy released during oxidation is carbon (C). Biomass C content is usually 45% to 50% (by oven-dried mass) (Schlesinger, 1991), but it may vary depending on the species and other factors. For instance, a 20% moisture content in raw biomass would reduce the C content to around 40% (Matthews, 1989). The species best suited for energy plantations are those that have high biomass production in dry weight, good sprouting, fast growth, narrow crowns or large-sized leaves in the upper crown, biomass with high specific energy and quality, adaptability to a wide range of sites, and resistance to biotic and abiotic agents (Gonçalves et al., 2018). In addition, N availability is a limiting factor for plant growth and development. Storage of N is among key processes in the economy of this nutrient, and its metabolic use determines vascular development and biomass production. The organically bound N content is also important because it is related to nitrogen-oxide emissions that result after combustion (Hadrović et al., 2021).

Numerous studies on the C storage by forests have been conducted in the past several decades (e.g., Matthews, 1989). However, the biomass C and N content in softwood broadleaves has remained insufficiently investigated, although it was studied by others (e.g., Pernar et al., 2012; Young, 1971). Hence, our study aims to investigate and compare six common softwood broadleaves based on their C and N storage capacity.

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Materials and Methods

Biomass samples (branches 10–20 cm long, >7 cm thick) of six softwood broadleaves were collected at six geographic points in southwestern Serbia: 1) common alder [*Alnus glutinosa* (L.) Gaertn.] (lat. 43.03016°N, long. 20.37445°E), 2) white willow (*Salix alba* L.) (lat. 43.13036°N, long. 20.42094°E), 3) black poplar (*Populus nigra* L.) (lat. 43.13863°N, long. 20.45961°E), 4) goat willow (*Salix caprea* L.) (lat. 42.98018°N, long. 20.48508°E), 5) silver birch (*Betula pendula* Roth) (lat. 43.29474°N, long. 20.13320°E), and 6) european aspen (*Populus tremula* L.) (lat. 43.063 56°N, long. 20.59872°E). Each species was represented by a sample plot, five individuals, and a sample per individual (total of 30 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 suitable mill. Sample weights of 30 mg were separated for C and N determination in a CHN analyzer (Elementar CHN analyzer Vario EL III, Hanau, Germany) according to standard procedure (AOAC International, 2006).

Raw data were used to calculate mean values of all parameters and to determine average ± SD for every mean. Determination of the difference between the means was carried out using analysis of variance (ANOVA) with post hoc Fisher's least significant difference test. A canonical discriminant analysis (CDA) was performed 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 Statgraphics (v. XVI.I.; Statpoint Technologies, Inc., Warrenton, VA).

Results and Discussion

All species studied had a greater N content and lesser C/N ratio in bark than in wood; in all species except in goat willow, the C content was greater in wood than in bark (Table 1), similar to the results of the investigation of fruit species in southwestern Serbia (Hadrović et al., 2021). 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 both studied elements and their ratios in bark, forming three homogeneous groups; in wood, only the C/N ratios contributed to the differentiation of species ($F = 3.24$, $P = 0.0225$). Comparing the means, the lowest N content in bark was found in black poplar, and the highest was found in european aspen; the lowest C content was found in common alder, and the highest was found in goat willow. In wood, the lowest C/N ratio was determined for common alder, and the highest was determined for black poplar (Table 1). However, as in Hadrović et al. (2019, 2021), the values were mostly lower than those stated in the literature (Schlesinger, 1991). The obtained mean of C content in the wood of goat willow fitted into the literature range (43.06% to 50.00%) (Gonçalves et al., 2018; Schlesinger, 1991), but in the wood of black poplar, european aspen, and silver birch and the wood and bark of common alder, it was less than the value recorded by Gonçalves et al. (2018), Matthews (1989), Pedišius et al. (2016), and Pernar et al. (2012). The N content in the wood of the analyzed species was greater than that stated by Gonçalves et al. (2018), Young (1971), and Pedišius et al. (2016). The same applies to the N content in the bark of common alder and silver birch, compared with the data given by Pernar et al. (2012) and Young (1971). Still, the C and N content in the bark of the analyzed species was generally greater than the content determined in the bark of conifer and fruit species in southwestern Serbia (Hadrović et al., 2019, 2021). Also, in wood, the C content was mostly greater and the N content was mostly less in the analyzed species than in the conifers and fruits, which makes these species better candidates for biomass production.

Table 1. Descriptive, univariate and multivariate statistics on carbon (C) and nitrogen (N) contents in the bark and wood of six softwood broadleaves in southwestern Serbia.

	Salix alba	*Salix caprea*	*Populus nigra*	*Populus tremula*	*Alnus glutinosa*	*Betula pendula*	CDA		ANOVA	
							CDA1	CDA2	F-ratio	*P* value
Cluster	1	3	2	1	1	1				
Eigenvalue	—	—	—	—	—	—	5.59	4.18	—	—
Percentage	—	—	—	—	—	—	52.45	39.24	—	—
Bark										
N (%)	1.92 ± 0.09 bc[z]	1.85 ± 0.10 c	1.76 ± 0.13 c	2.30 ± 0.18 a	1.85 ± 0.08 c	2.07 ± 0.16 b	0.42	**−0.82**[y]	11.48	**0.0000**
C (%)	41.26 ± 2.30 bc	47.21 ± 2.55 a	40.57 ± 3.03 bc	43.21 ± 2.57 b	38.78 ± 1.90 c	39.97 ± 2.87 bc	**−0.89**	−0.11	6.94	**0.0004**
C/N	21.50 ± 1.44 bc	25.50 ± 2.57 a	23.00 ± 2.87 ab	18.80 ± 2.14 c	21.00 ± 1.59 bc	19.30 ± 2.12 c	**−0.96**	−0.03	6.46	**0.0006**
Wood										
N (%)	1.20 ± 0.13 a	1.30 ± 0.15 a	1.10 ± 0.19 a	1.23 ± 0.10 a	1.26 ± 0.22 a	1.24 ± 0.09 a	0.06	0.02	0.99	0.4458
C (%)	42.94 ± 2.93 ab	45.25 ± 3.00 a	42.43 ± 1.62 ab	43.89 ± 2.60 ab	41.34 ± 1.97 b	43.51 ± 2.66 ab	−0.32	**−1.16**	1.41	0.2575
C/N	35.80 ± 2.68 ab	34.90 ± 2.16 bc	38.50 ± 1.72 a	35.70 ± 2.54 abc	32.80 ± 1.34 c	35.10 ± 2.88 bc	**1.00**	**1.45**	3.24	**0.0225**

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

[y]Bold values denote variables with discriminant function coefficients >0.70 for canonical discriminant analysis (CDA), and $P < 0.05$ for analysis of variance (ANOVA).

The critical N amount in biomass is 1% to 2%, and it can be affected by removing bark, which in softwoods participates with 6% to 18% (Nosek et al., 2016).

In the CDA, the first function accounted for 52.45% of the discrimination, and the second one discriminated another 39.24%. The contents of C and N and their ratios, with discriminant function coefficients >0.70, are responsible for the differentiation along both axes, which resulted in the differentiation of species. Similar to the results of ANOVA, three 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. Specifically, the results suggest that, at least in the area of southwestern Serbia, goat willow has a high potential for C storage compared with white willow, european aspen, common alder, silver birch, and black poplar, representing a promising softwood broadleaf for biomass cropping. Biomass could also be obtained from pruning operations that take place in parks and gardens where the species' cultivated variants are grown. On the other hand, being a small tree or shrub, it might be less productive, and black poplar, which has the best C/N ratio in wood, could be used instead. These data should be considered an important factor in selecting softwood broadleaves for biomass production.

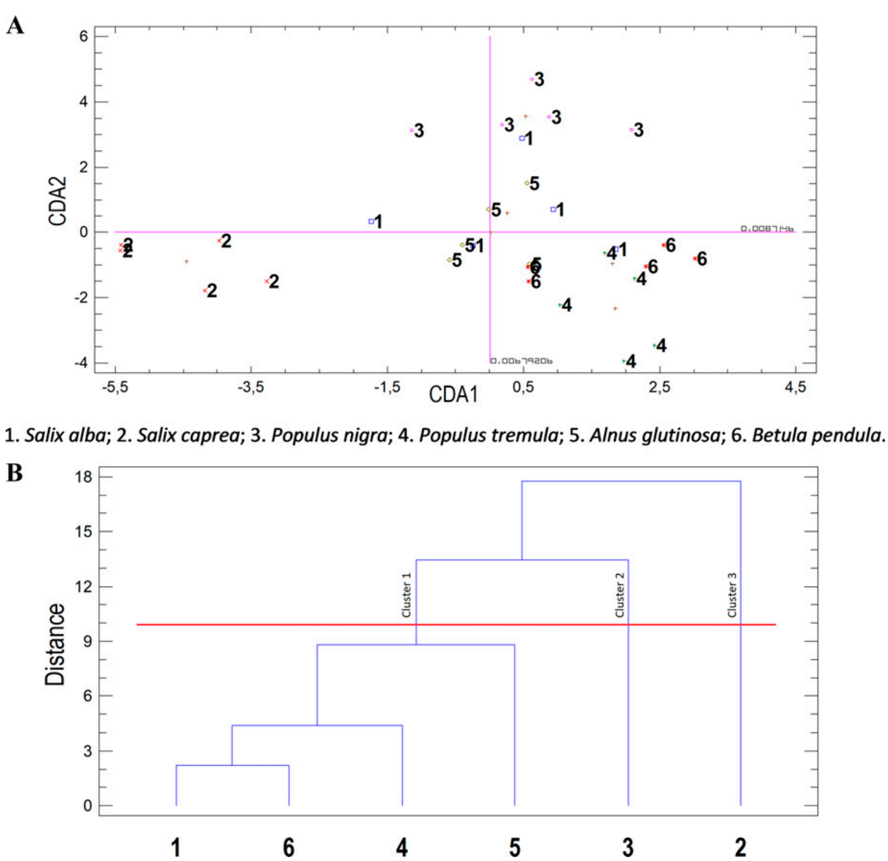

Fig. 1. (**A**) Canonical discriminant analysis (CDA) scatterplot and (**B**) dendrogram of six softwood broadleaves based on the carbon and nitrogen content in their bark and wood.

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