Chemical Composition and Stocks of Nutrients in Dead Wood of Beech (Fagus Sylvatica L.) Forests

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Abstract: - The research was carried out in four beech communities in two mountains, Stara Planina and Vitosha in Western Bulgaria. The object of the study was dead beech wood. The aim was to determine the chemical composition and stocks of nutrients in different parts of dead wood in both mountains. The content of macro- and micronutrients in different fractions (stumps, standing, and lying dead wood) of dead wood was determined. The elements carbon (C), hydrogen (H), and nitrogen (N) were in the largest quantities of all the chemical elements studied. Next in order were Ca, Mg, K, and P. Micronutrients were arranged as follows in descending order of their content in the dead wood: Mn, Fe, Zn, Na, Pb, Cu. The calculated stocks of these elements showed that Stara Planina had a larger stock of elements than Vitosha mountain due to the greater amount of dead wood. The results proved that the dead wood is primarily a carbon reservoir, stored mainly in the lying dead wood fraction. The average carbon stock was 983 kg/ha for Vitosha and 4635 kg/ha for Stara Planina. The stocks of all other elements that are contained were several times less in quantity.

Key-Words: - dead wood, common beech, macronutrients, micronutrients, stocks of elements, chemical composition

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1 Introduction

The content of macro- and micronutrients in different fractions of plant biomass is the subject of many investigations, [1], [2]. Many authors studied the content of chemical elements in a litterfall as a dynamic fraction, [3], [4]. Deadwood plays an important role in keeping of biodiversity, [5], soil fertility, and carbon sequestration, [6]. There is an opinion that lowlands dead wood has significantly higher functions than mountain reserves, especially to damage caused by windstorms, [7]. According to [7], the fallen dead wood contributed more to the total dead wood volume than standing dead wood. In the same paper, [7], the authors found that standing dead wood was almost twice as high in the mountain than in lowland forest reserves (45% versus 25%).

Dead wood is one of the main stocks of carbon and nitrogen in forest ecosystems. These elements are returned through decomposition processes as essential nutrients for the decomposer organisms, [5]. Bacteria and fungi play active and complementary roles in decomposition processes. A dynamic of the decomposition and cycle of mineral nutrition is used to predict and prevent possible stress in forest ecosystems and understand mechanisms of their adaptation to environmental conditions, [8], [9]. Long-term monitoring of dead wood dynamics is essential to determine material cycling in ecosystems. Dead wood plays a role in nitrogen cycling through the processes of nitrogen fixation and immobilization, [10]. Fresh dead wood usually has low nitrogen content. During decomposition, the N content in deadwood increases, [11]. The main reason for that change according to [12], is nitrogen fixation from the atmosphere. Results of investigation in Mediterranean mountain forests show an increase in nitrogen content during the decay process, while the carbon content in stumps remains stable, [13]. The loss of carbon by respiration during the decomposition processes is mentioned in [14]. According to [15], concentrations of some chemical elements increase during the decomposition process with the exception of potassium or the number of nutrients in logs increases. Some authors, [16], argue that there is a difference in the concentration of some nutrients (Ca and P) according to the decay classes and among species for elements K, P, and Mg.

This paper aims to determine chemical elements in different parts of the dead wood (standing, laying, and stumps) in two mountains in Western Bulgaria and to calculate their stocks as a reservoir of macro- and micronutrients.

2 Problem Formulation

2.1 Objects

2.1.1 Site Description

The study was carried out in four mountain sites in Western Bulgaria. Two sample plots were selected in Vitosha mountain: Tihia kat (SP1), located in the northwest at 1100 m a.s.l. and Zlatni Mostove (SP2), located in the south-west at 1400 m a.s.l. There were also two sample plots in Stara Planina: Petrohan (SP3), located in the east-south at 1480 m a.s.l. and Barzia (SP4), located in the northeast at 630 m a.s.l. The climate is temperate continental and mountainous and the soils are Cambisols. The objects of the investigation were standing, lying dead wood and stumps in common beech (Fagus sylvatica L.) communities in the two mountains. The location of the studied sites is shown in Fig.1.

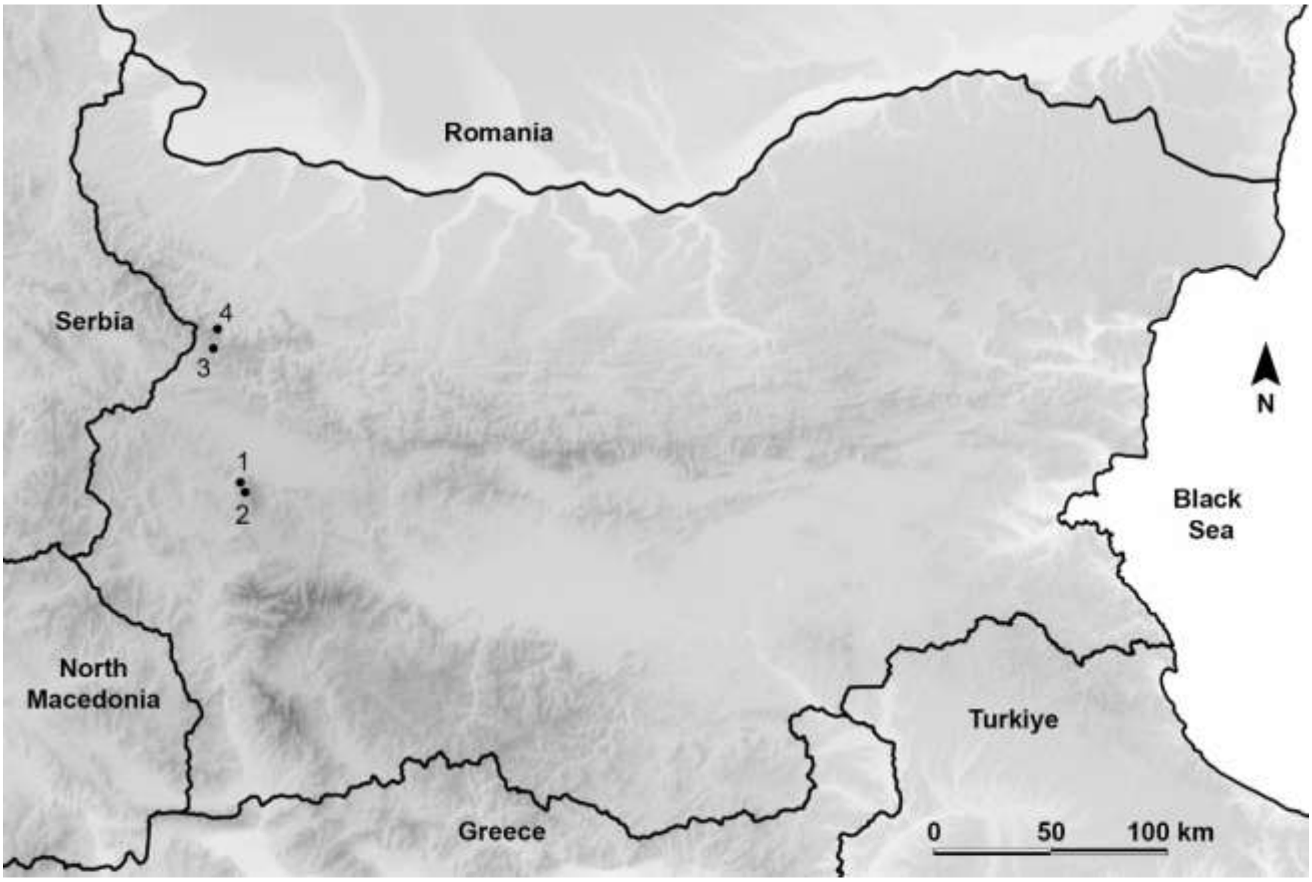

Fig. 1: Site location

2.2. Materials and Methods

2.2.1. Chemical Analyses

The content of elements was determined in three different fractions of dead beech wood – stumps, standing, and lying wood. Average samples of these fractions were formed for each site. The wood was ground to a powder with a size of 0.25 mm using a grinding mill. Main components such as carbon, nitrogen, and hydrogen were determined by Automatic Element Analyzer Euro EA3000 type CHNSO, SINGLE. For determination of general phosphorous and metal content, samples were digested by heating in a Muffle furnace at 450˚C for 4 hours. The dry residues were dissolved into 20% hydrochloric acids. Phosphorous was measured spectroscopically at 410 nm after forming a phosphorous-vanadium-molybdate complex using a spectrophotometer Lambda 5. Metals were measured using atomic absorption spectrometry (Perkin Elmer AAS) of the solutions. The moisture of the samples was measured using a moisture-measuring balance.

2.2.2. Estimation of the Mineral Amount

The elements' content was calculated by multiplying the concentration of every element and the amount of wood for the corresponding site. All results are shown as an absolutely dry mass by correcting with coefficients corresponding to their moisture content.

3 Problem Solution

Macronutrients in plants are: organic carbon, nitrogen, phosphorous, hydrogen, calcium, potassium, magnesium, sodium, sulfur, and silicon. In the present study, information was obtained on most of them. The main structural element of wood is organic carbon. The determined carbon content in the dead wood for all the sampling plots was the highest of all the chemical elements examined. That result was found by many other researchers, [6], [10], [13], [14]. Carbon content varied widely between 47% and 70% absolute dry mass (Table 1, Table 2, Table 3, Table 4).

Table 1. Elements' content in dead wood of Tihia kat (SP1) in mg/kg absolute dry mass

Dead wood	C, %	N, %	H, %	P, mg/kg	Fe, mg/kg	Pb, mg/kg	Cu, mg/kg	Mn, mg/kg	Zn, mg/kg	Mg, mg/kg	Ca, mg/kg	Na, mg/kg	K, mg/kg
standing	47.10	1.74	7.23	260.70	38.6	16.60	11.25	438.6	15.7	3699.8	15575.0	20.3	13112.3
stumps	58.39	2.00	10.79	251.67	97.8	8.58	7.00	229.5	17.5	1250.9	6736.7	17.5	1216.5
lying	53.75	1.11	7.14	184.97	111.9	4.24	6.42	40.3	19.6	317.5	3642.9	9.5	187.3

Table 2. Elements' content in dead wood of Zlatni Mostove (SP2) in mg/kg absolute dry mass

Dead wood	C, %	N, %	H, %	P, mg/kg	Fe, mg/kg	Pb, mg/kg	Cu, mg/kg	Mn, mg/kg	Zn, mg/kg	Mg, mg/kg	Ca, mg/kg	Na, mg/kg	K, mg/kg
standing	70.23	2.29	9.82	621.94	176.1	7.12	5.63	312.7	15.2	934.1	6812.3	47.7	3209.0
stumps	63.64	2.15	8.00	604.0	195.4	7.91	7.73	176.95	22.85	558.53	7372.84	20.59	998.44

Table 3. Elements' content in dead wood of Petrohan (SP3) in mg/kg absolute dry mass

Dead wood	C, %	N, %	H, %	P, mg/kg	Fe, mg/kg	Pb, mg/kg	Cu, mg/kg	Mn, mg/kg	Zn, mg/kg	Mg, mg/kg	Ca, mg/kg	Na, mg/kg	K, mg/kg
standing	61.31	1.92	9.01	740.33	127.7	8.77	4.54	419.3	60.5	846.2	5298.0	18.9	1176.5
stumps	52.03	1.79	8.21	312.37	101.4	12.11	7.15	391.0	63.5	1512.5	10464.1	13.4	493.0
lying	58.20	1.01	10.79	94.68	22.4	0.53	1.55	103.9	5.3	162.3	1354.4	7.5	166.3

Table 4. Elements' content in dead wood of Barzia (SP4) in mg/kg absolute dry mass

Dead wood	C, %	N, %	H, %	P, mg/kg	Fe, mg/kg	Pb, mg/kg	Cu, mg/kg	Mn, mg/kg	Zn, mg/kg	Mg, mg/kg	Ca, mg/kg	Na, mg/kg	K, mg/kg
Standing	54.08	1.15	7.65	92.54	59.5	1.08	1.19	44.4	3.2	125.0	444.7	7.0	77.4
Stumps	50.79	2.09	9.93	663.23	101.4	12.25	9.21	671.5	24.0	2071.5	11382.0	19.5	1354.5

The highest amount of carbon was determined in standing dead wood compared to the other fractions, except for sampling plot 1. For it, the carbon content was highest in stumps. The next element in content was hydrogen. Its amount varied between 7.65% and 10.79% absolute dry mass (Table 1, Table 2, Table 3, Table 4). There is no clear trend in which a fraction of the hydrogen content was dominant. The stumps in SP1 (Table 1) and SP4 (Table 4) contained more hydrogen than the other fractions. The same trend was found for nitrogen content for the same plots. For sampling plot 3 (Table 3), higher nitrogen content was found in standing dead wood. The lowest nitrogen content was 1.01% absolute dry mass and was measured in lying wood in SP3 (Table 3). For SP1, the same fraction had the least amount of nitrogen (Table 1). The degree of stump decomposition in SP1 and SP4 was the greatest compared to the remaining sites. The increased amount of nitrogen during the decomposition processes has been confirmed by other studies, [11], [12].

Calcium was in fourth place according to its quantity among the chemical elements studied. It is responsible for the synthesis of new cells and the hardness of trees. That is why the calcium content of the wood was so high. The highest amount of calcium was determined for SP1 (Table 1) in standing wood. The measured amount of this element for the all rest sampling plots was higher in stumps (Table 2, Table 3, Table 4). Probably the degree of decomposition of the wood determines the greater content of calcium in the stumps, as mentioned in [16]. According to [9], the elements calcium and magnesium in living trees are antagonists, i.e. when one element is in greater quantity the other is in less and vice versa. What we found was that the element magnesium was contained in similar quantitative ratios in the same fractions as calcium, except for SP2 (Table 2).

Potassium and phosphorous contents were higher in standing wood, except for SP4 (Table 4). The least amount of them was in the lying dead wood. Our results confirmed the opinion of the authors in [15], that the established K content in the stumps did not increase during the decomposition processes.

The last of the macronutrients studied, sodium, was found in the least amount in wood. Its content in SP2 was almost double (Table 2) compared to the other sampling plots. That site was near the road and may have been leftover sodium salt used in the winter to prevent icing on the roads.

The results obtained for SP4 were an exception to those for the other sites. On the one hand, the decomposition rate of standing wood in SP4 was low, on the other hand, the degree of decomposition of stumps was very high. This may be the reason for such a large difference in the trends found for nutrients in the study's four sites. All chemical elements were determined to be lower in standing deadwood than in stumps for SP4.

About 25% of heavy metals are micronutrients (Fe, Mn, Cu, Zn, Mo, Co). They exist in plants in extremely small amounts. Manganese content varied widely and the highest values were found in standing dead wood, except in SP4 (Table 4). For the content of the element iron, no relationship could be found between the different fractions. For example, its amount is highest in lying wood only in SP1, for SP3 in standing wood, and for SP2 and SP4 - in stumps.

The biggest difference was found in the values for lead. The amount of lead was almost the same in all fractions for SP2 in Vitosha (Table 2), while in the standing wood in the other plot of the same mountain (Table 1), its content was more than double. For the sampling plots 3 (Table 3) and 4 (Table 4), lead dominated in stumps. Higher values were measured for plots located next to roads. As [17], found, this metal was deposited around roads during the period of its use as a fuel additive and could not disappear because plants had not mechanisms for its dissimilation. Zink element dominated in standing wood and stumps of Petrohan (Table 3), while in the other plots, its amount was within the close limits and 3-4 times lower. The element copper was presented in the dead wood in the least amount among all the elements examined. Its content varied widely between 1.19 mg/kg to 11.25 mg/kg. Its largest amount was found in the dead wood in Vitosha, SP1 (Table 1).

A previous study in the Western Stara Planina by a member of this paper, [18], confirmed the trends presented for the SP3 and SP4. The data were not the same, but trends were similar.

The average stocks of the studied elements in the dead wood in both mountains are presented in Table 5. When comparing the values of the amount of the elements, we can conclude that Stara Planina had a larger stock of elements than Vitosha, due to a larger amount of dead wood. The main nutrient reservoir was the lying dead wood for the all study sites, regardless of their altitude. Our results proved conclusions in [6], [7], [16], that the dead wood was a major reservoir of carbon. That element was stored mainly in the lying dead wood of both mountains. The carbon stock was 1763 kg/ha for Vitosha Mountain and 4635 kg/ha for Stara Planina.

All other elements that were contained were several times less amount as stocks.

Table 5. Stocks of elements in dead wood in Vitosha and Stara Planina mountains in kg/ha absolute dry mass

ELEMENTS	VITOSHA			STARA PLANINA		
	Standing wood	**Stumps**	**Lying wood**	**Standing wood**	**Stumps**	**Lying wood**
Organic carbon (C)	959.186	226.380	1762.6	3504.937	1622.672	8776.560
Nitrogen (N)	30.563	7.654	36.4	83.545	61.616	152.308
Hydrogen (H)	135.376	29.245	234.138	500.731	288.422	1627.132
Potassium (K)	6.52	0.362	0.614	2.094	3.013	2.503
Calcium (Ca)	11.45	2.622	11.946	9.893	34.607	20.424
Phosphorus (P)	0.819	0.208	0.607	1.529	1.580	1.428
Sodium (Na)	0.063	0.007	0.062	0.061	0.053	0.113
Lead (Pb)	0.012	0.003	0.014	0.019	0.033	0.008
Magnesium (Mg)	1.875	0.216	8.117	1.840	5.723	2.447
Copper (Cu)	0.009	0.003	0.021	0.012	0.026	0.023
Iron (Fe)	0.225	0.068	0.367	0.474	0.320	0.338
Manganese (Mn)	0.472	0.064	0.132	0.827	1.709	1.567
Zink (Zn)	0.022	0.008	0.064	0.104	0.134	0.080

Lying wood also stored hydrogen and nitrogen in higher amounts than standing wood and stumps (Table 5). The average hydrogen stock was 125 kg/ha and 805 kg/ha for Vitosha Mountain and Stara Planina, respectively. For nitrogen stocks, the corresponding values were 23 and 99 kg/ha. Nitrogen stocks in the lying and standing dead wood in Vitosha mountain were comparable (Table 5), while stocks of lying dead wood in Stara Planina were almost twice as high as those of standing dead wood. In Stara Planina, Ca, and K were stored mainly in stumps, while in Vitosha mountain, the standing and lying wood stored almost the same amount of calcium, but K was mostly in the standing dead wood (Table 5). The average calcium stocks were 22 and 9 kg/ha for Stara Planina and Vitosha Mountain, respectively. The only element represented in slightly larger quantities in Vitosha mountain than in Stara Planina was magnesium. Its amount was 3.4 and 3.3 kg/ha, respectively. In addition, in Vitosha it was stored in standing and lying dead wood, while in Stara Planina mainly in stumps. The last major nutrient element, phosphorus, was stored in Stara Planina in three times greater quantity (1.5 kg/ha) than in Vitosha mountain (0.5 kg/ha). Its stock was the highest in the stumps in Stara Planina, while in Vitosha mountain – in the standing dead wood (Table 5). According to [16], the net release of nutrients varies over a wide range from 31% (N) to 93% (K). This makes it difficult to compare results if the decay classes of the dead wood are not known.

All micronutrients (Mn, Fe, Na, Cu, Pb) had stocks of less than a kilogram per hectare, except manganese, which amount in Stara Planina was 1.4 kg/ha and in Vitosha 0.2 kg/ha only. It was mainly stored in the stumps in Stata Planina, while in Vitosha mountain – in the standing dead wood. All micronutrients (Mn, Fe, Zn, Na, Cu, Pb) have reserves below a kilogram per hectare, except for manganese, the amount of which in Stara Planina was 1.4 kg/ha and in Vitosha only 0.2 kg/ha. Their entire stock was 2 kg/ha in Stara Planina and 0.5 kg/ha in Vitosha.

4 Conclusion

The order of the studied element in the dead wood was as follows: C > H > Ca > Mg > K > P > Mn > Fe > Zn > Na > Pb > Cu. Comparing the amount of elements stored in the dead wood we can conclude that Stara Planina had a greater stock of elements than Vitosha Mountain due to the greater amount of dead wood. The main nutrient reservoir was the lying dead wood for Vitosha mountain. For Srtara Planina, stocks of K, Ca, P, and Mg were mostly in the stumps. The stocks of main nutrients, organic carbon, hydrogen, and nitrogen were in the lying dead wood for both mountains. All other elements contained were several times less amount as stocks.

The dead wood of both mountains was a major reservoir of carbon. The sum carbon stock was 2948 kg/ha for Vitosha and 13904 kg/ha for Stara Planina. The sum hydrogen stock was 399 kg/ha and 2416 kg/ha for Vitosha and Stara Planina, respectively. For nitrogen reserve, the corresponding values were 75 kg/ha for Vitosha Mountain and 297 kg/ha for Stara Planina. The sum calcium stocks were 26 and 65 kg/ha, respectively. The sum of magnesium stocks in both mountains was almost the same – in Vitosha 10.2 kg/ha and Stara Planina 10.0 kg/ha. The sum of phosphorous stock was 1.6 and 4.5 kg/ha. The total supply of micronutrients (Mn, Fe, Zn, Na, Cu, Pb) was 5,9 kg/ha in Stara Planina and 1.6 kg/ha in Vitosha.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

-Sonya Damyanova carried out the calculation and representation of the results.
-Violeta Dimitrova organized and executed the experiments.

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Conflict of Interest

The authors have no conflict of interest to declare.

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