Chemical Composition of Litterfall in Beech (*Fagus sylvatica* L.) Forests

VIOLETA DIMITROVA[1], SONYA DAMYANOVA[2]
[1]Forestry Department,
University of Forestry,
Kliment Ohridski Blv., 10, 1797, Sofia,
BULGARIA

[2]Ecology and Landscape architecture Department,
University of Forestry,
Kliment Ohridski Blv., 10, 1797, Sofia,
BULGARIA

Abstract: - The quantity and quality of litterfall in forests play an important role in their condition. Through it, a large part of the chemical elements are returned to the cycle of the ecosystem, it is an essential carbon depot, it affects regeneration, soil moisture, fertility, composition, fauna, and flora. The present study aims to evaluate the role of the litterfall as a depot of chemical elements. The total annual amount of elements returned to the beech forest ecosystem is 1264.97 kg.ha^{-1}, of which macroelements are 1257.79 kg.ha^{-1}, and microelements - are 7.19 kg.ha^{-1}. The predominant elements are: carbon - about 80%, hydrogen - about 13%, nitrogen - 3%, and calcium - 2%. The remaining elements are represented in very small amounts – less than 1%. Microelements are presented in the following sequence: Mg >Mn >Fe >Zn >Pb >Cu.

Key words: - Litterfall, chemical elements, common beech communities

Received: November 13, 2022. Revised: March 16, 2023. Accepted: April 11, 2023. Published: May 3, 2023.

1 Introduction

The quantity and quality of litter in forests play an important role in their condition. It affects regeneration, soil moisture, fertility, composition, fauna, and flora, [1], [2]. Through it, a large part of the chemical elements are returned to the cycle of the ecosystem, it is an essential carbon depot, [3], [4], [5], [6], [7]. According to some authors, [8], almost 80% of net primary production is returned to the ecosystem through litterfall.

Based on the number of different fractions, conclusions are made about the influence of climate on the phenophases of tree species. This indicator is also included as a component of forest monitoring,

In Bulgaria, studies of the chemical composition of the litter in beech forests were done by [16], [17].

This study is part of a project "Structure and ecological functions of dead biomass in beech forests (*Fagus sylvatica* L.) in Western Bulgaria".

[9]. Questions related to the rate of decomposition, the organisms involved in this process, as well as the dynamics of the elements are addressed, [10], [11], [12], [13]. The effect of heavy metals and nutrients on respiration rates of forest litter has been studied, [14].

Most studies of litterfall are in managed forests, while, [15], were conducted in Romanian virgin beech forests mixed with Scots fir, looking for relationships with leaf area index. The authors conclude that in mixed forests, annual leaf fall is more closely related to stand characteristics than to leaf area index. 3,5 t. ha^{-1} were obtained as average litterfall amounts.

2 Problem Formulation

The present study aims to evaluate the role of litterfall as a depot of chemical elements within the framework of the above-mentioned project. The task is to see what elements and in what quantities are returned through the litterfall to the turnover of the

ecosystem. The research is a way to clarify the principles of the functioning of forest communities.

2.1 Object of Investigation

The object of investigation was common beech (*Fagus sylvatica* L.) communities in Vitosha and Stara Planina mountains in Bulgaria (Fig. 1). The climate is temperate continental and mountainous. The soils are Cambisols.

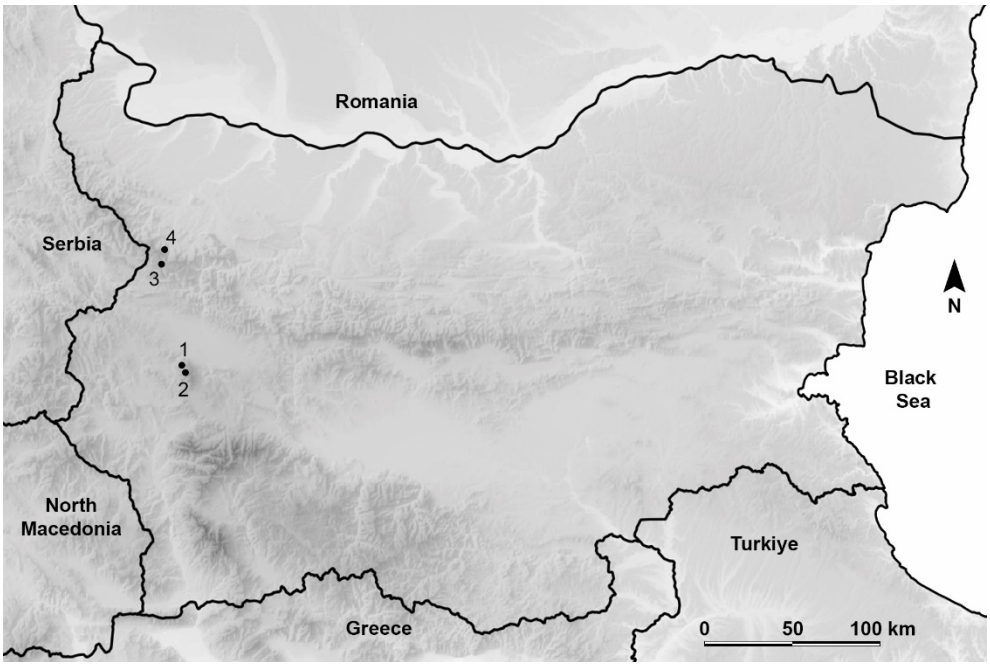

Fig.1: Location of the sample plots

The characteristics of the beech stands are presented in Table. 1.

Table 1. Stands characteristics in the sample plots.

Sample plot	Altitude, m	Geographic coordinates	Age, years	Canopy	Average height, m	Average diameter, cm
Vitosha, Tihia kat, SP 1	1100	N 42,63131 E 23,22438	90	0.7	23	30
Vitosha, Zlatni mostove, SP 2	1400	N 42,61275 E 23,23578	110	0.7	25	40
Stara planina, Petrohan, SP 3	1480	N 43° 07' 21.8" E 23° 07' 17.3"	120	1	27	30
Stara planina, Barzia, SP 4	630	N 43° 10' 39.4" E 23° 09' 11.8"	130	1	29	38

2.2 Methods

2.2.1 Chemical Analyses

To determine elements in the litter fall, an average sample from 3 collectors for each site was formed. Biomass was ground to a powder 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 Mineral Quantities

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

3 Problem Solution

As a result of the conducted research, data were obtained about amounts of macro and microelements in leaf litter in beech forests, which are listed in Table 2.

Table 2. Chemical elements in leaf litter in beech forests (a. d. m., $mg.kg^{-1}$).

Elements	SP 1 Vitosha, Tihia kat	SP 2 Vitosha, Zlatni mostove	SP 3 Stara planina, Petrohan	SP 4 Stara planina, Barzia
Organic carbon (C)	458100	468400	493300	491900
Nitrogen (N)	15200	17300	19600	18400
Phosphorus (P)	339.474	655	1218.127	560.865
Potassium (K)	4842.34	3576.3	5910.398	3569.14
Hydrogen (H)	89500	73300	77300	77600
Calcium (Ca)	11998.6	13468.9	7999.12	9304.85
Sodium (Na)	28.756	30.392	51.808	25.304
Total macroelements	**580009**	**576731**	**605379.5**	**601360**
Lead (Pb)	12.524	14.672	7.869	8.851
Magnesium (Mg)	2155.91	1936.7	1205.03	2292
Copper (Cu)	4.891	4.297	4.973	4.181
Iron (Fe)	185.438	150.912	153.567	142.266
Manganese (Mn)	1241.63	1397.51	1308.32	1356.96
Zink (Zn)	30.638	36.68	29.511	25.195
Total microelements	**3631.03**	**3540.77**	**2709.27**	**3829.45**
Total	**583640.2**	**580271.4**	**608088.72**	**605189.6**

The average amounts of the elements for Vitosha Mountain are $58,2.10^4$ mg.kg^{-1}. The sum of macroelements ($57,8.10^4$ mg.kg^{-1}) significantly exceeds the number of microelements ($0,3.10^4$ mg.kg^{-1}). Carbon predominates of the macroelements, - $46,3.10^4$ (mg.kg^{-1}), and of the microelements – magnesium (Fig. 2). Trace elements are in the following sequence: Mg >Mn >Fe >Zn >Pb >Cu. No significant differences in the number of elements were observed between the two sample plots.

The average amounts of elements for the sample plots in the Western Stara Planina are $60,7.10^4$ mg.kg^{-1}. Here, too, the main amount of elements are the macroelements ($60,3.10^4$ mg.kg^{-1}), and the microelements are an insignificant amount ($0,4.10^4$ mg.kg^{-1}). The largest percentage is represented by carbon, and the smallest by sodium From the macroelements (Fig. 2). The trace elements are in the same sequence as in Vitosha. Between the two sample plots, no significant differences in the number of elements are observed here either.

When comparing the average results from the two mountains, it can be seen that the lead is significantly more in the sample areas in Vitosha. A possible reason could be their proximity to a road. The percentage ratios of all elements are similar (Fig.2). The predominant elements are: carbon - about 80%, hydrogen - about 13%, nitrogen - 3%, and calcium - 1%. The remaining elements are represented in very small amounts – less than 1%.

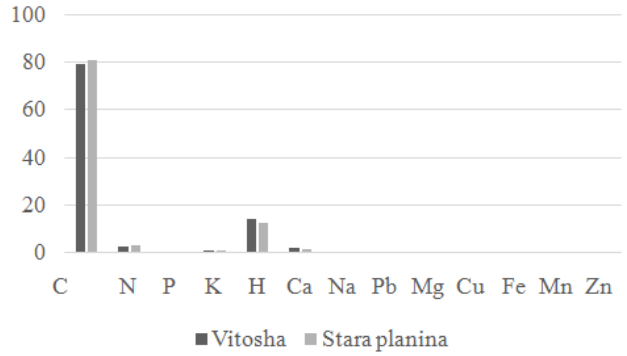

Fig. 2: Percentage distribution of the studied elements in beech leaf litter in Vitosha and Stara Planina. The stores of leaf litter for Vitosha are respectively SP 1 – 157,54 g.m^{-2}, SP 2 – 172,56 g.m^{-2}, and for Western Stara Planina – SP 3 – 262,57 g.m^{-2}, SP 4 – 254,89 g.m^{-2}. Detailed information on the amounts of litterfall and its fractions is available in a publication by [18].

In recent decades, the litterfall in forest ecosystems has received increasing attention. Many authors discuss the topic, such as [7], who investigated the amount and chemical composition of litter in Eastern beech (*Fagus orientalis* Lipsky) forests in Turkey. In this case, average amounts of litterfall between 3602-6160 kg.ha^{-1} were obtained. The leaves are 62% of all litterfall. The measured concentrations in the leaves were lower than our results for: P -138,373 mg.kg^{-1}, K – 1416,5 mg.kg^{-1}, Pb – 1,387 mg.kg^{-1}, Zn- 13,333 mg.kg^{-1}; higher for Na – 187,993 mg.kg^{-1} and approximately the same for: Ca – $10,4.10^3$, Mg – $1.3.10^3$, Cu – 4,27 mg.kg^{-1}, Fe – 130,75 mg.kg^{-1}, Mn- $1,6.10^3$ mg.kg^{-1}.

In our previous studies of litterfall in beech forests, the following amounts of elements were obtained in the leaves: carbon – 35.10^4 mg.kg^{-1}, nitrogen – $1,2.10^4$ mg.kg^{-1}, phosphorus – 780 mg.kg^{-1} calcium – $1,6.\ 10^4$ mg.kg^{-1}, Mg – $1,1.10^4$ mg.kg^{-1}, copper – 8,1 mg.kg^{-1}, iron – 222,3 mg.kg^{-1}, Mn – 591,7 mg.kg^{-1}, iron – 48,1 mg.kg^{-1}, [17]. The results are comparable to those obtained in the present study.

The average annual stocks of elements in Vitosha are 960.52 kg.ha^{-1}, and in Stara Planina, they are 1569.42 kg.ha^{-1} (Table 3).

Table 3. Annual stocks of elements in leaf litter (a.d.m, kg.ha^{-1}).

Elements	Vitosha	Stara planina
Organic carbon (C)	764.59	1274.41
Nitrogen (N)	26.82	49.15
Phosphorus (P)	0.82	2.3
Potassium (K)	6.94	12.62
Hydrogen (H)	134.35	200.37
Calcium (Ca)	21.01	22.38
Sodium (Na)	0.05	0.09
Total macroelements	**954.59**	**1560.98**
Lead (Pb)	0.02	0.02
Magnesium (Mg)	3.38	4.52
Copper (Cu)	0.01	0.01
Iron (Fe)	0.28	0.38
Manganese (Mn)	2.18	3.45
Zink (Zn)	0.06	0.07
Total microelements	**5.92**	**8.46**
Total	**960.52**	**1569.42**

A comparison of our results for the annual sums of the elements with those obtained by other authors also shows a similarity in amounts. For example, in similar previous studies, [16], elements in leaf litter were studied, and the values were: N – 28,2 kg.ha^{-1}, Ca – 16,2 kg.ha^{-1}, K – 7,4 kg.ha^{-1}, Pb – 0.001 kg,ha^{-1}, Zn – 0,044 kg.ha^{-1}, Mn – 1,878 kg.ha^{-1} and Fe – 0,305 kg.ha^{-1}. They are closer to those established for Vitosha Mountain. In the Stara Planina, the annual amounts are slightly higher, due to the greater amount of litterfall found.

4 Conclusion

The average annual reserves of the elements that return to the beech forest ecosystem are 1264,97 kg.ha^{-1}, of which macroelements are 1257,79 kg.ha^{-1}, and microelements – are 7,19 kg.ha^{-1}. The predominant elements are: carbon - about 80%, hydrogen - about 13%, nitrogen - 3%, and calcium - 2%. The remaining elements are represented in small amounts - less than 1%. Microelements are presented in the following sequence: Mg >Mn >Fe >Zn >Pb >Cu.

During future research, it will be examined forest mulch (weight and composition) to determine the element's turnover rates.

As a result of the conducted research, it can be concluded that the leaf litter represents a significant depot of elements, with the largest percentage being carbon.

Acknowledgments:
The studies were funded by the project: "Structure and ecological functions of dead biomass in beech forests (*Fagus sylvatica* L.) in Western Bulgaria", КР – 06-Н54/1, 2021, Ministry of Education and Science, Scientific Researches Fund.

References:

[1] Sayer, E., Using experimental manipulation to assess the roles of leaf litter in the functioning of forest ecosystems, *Biological Reviews*, V. 81(1), 2006, pp.1-31.

[2] Langenbruch, C., Helfrich, M., Flessa, H., Effects of beech (*Fagus sylvatica*), ash (*Fraxinus excelsior*) and lime (*Tilia* spec.) on soil chemical properties in a mixed deciduous forest, *Plant and Soil*, V. 352 (1-2), 2012, pp. 389-403.

[3] Kavvadias, V.A., Alifragis, D., Tsiontsis, A., Brofas, G., Stamatelos, G., Litterfall, litter accumulation and litter decomposition rates in four forest ecosystems in northern Greece, *Forest Ecology and Management*, V.144(1), 2001, pp.113-127.

[4] Hansen, K., Vesterdal, L., Schmidt, I.K., Gundersen, P., Sevel, L., Bastrup-Birk, A., Pedersen, L.B., Bille-Hansen, J., Litterfall and nutrient return in five tree species in a common garden experiment, *Forest ecology and management*, V. 257(10), 2009, pp. 2133-2144.

[5] Meier, I., Leuschner, C., Hertel, D., Nutrient return with leaf litter fall in *Fagus sylvatica* forests across a soil fertility gradient, *Plant Ecology*, V. 177(1), 2005, pp. 99-112.

[6] Ukonmaanaho, L., Merilä, P., Nöjd, P., Nieminen, T., Litterfall production and nutrient return to the forest floor in Scots pine and Norway spruce stands in Finland, *Boreal Environment Research*, V. 13, 2008, pp. 67-91.

[7] Çakır M., Akburak. S., Litterfall and nutrients return to soil in pure and mixed stands of oak and beech. *Journal of the Faculty of Forestry Istanbul University*, V. 67(2), 2017, pp. 185-200.

[8] Kassnacht, K., Gower, S., Interrelationships among the edaphic and stand characteristics, leaf area index, and aboveground net primary production of upland forest ecosystems in north central Wisconsin, *Canadian Journal of Forest Research*, V. 27(7), 1997, pp.1058-1067.

[9] ICP-Forests. Sampling and Analysis of Litterfall. Hamburg, Germany, 2010.

[10] Austin, A., Vivanco, L., Plant litter decomposition in a semi-arid ecosystem controlled by photodegradation, *Nature*, V. 442(7102), 2006, pp. 555-558.

[11] Berg, B., McClaugherty, C., *Plant litter: decomposition, humus formation, carbon sequestration*. Springer-Verlag, Berlin Heidelberg, 2014.

[12] Hristovski S., Berg B., Melovski L., Limitless decomposition in leaf litter of common beech: Patterns, nutrients' and heavy metal's dynamics, *Pedobiologia*, Vol. 57 (3), 2014, pp. 131-138.

[13] Sarginci M., Yildiz O., Tolunay D., Toprak B., Temür Ş., Leaf litter dynamics in Western Black Sea mountainous forest ecosystems. *Canadian Journal of Forest Research*, 2021, https://doi.org/10.1139/cjfr-2020-0489

[14] Laskowski R., Maryanski M., Niklihska M., Effect of heavy metals and mineral nutrients on forest litter respiration rate, *Environ. Pollut.*, 84(1), 1994, pp. 97-102. doi: 10.1016/0269-7491(94)90076-0

[15] Petritan I., V. Mihăilă, C. Bragă, M. Boura, D. Vasile, A. Petritan, Litterfall production and leaf area index in a virgin European beech (*Fagus sylvatica* L.) – Silver fir (*Abies alba* Mill.) forest. *Dendrobiology*, V. 83, 2020, pp. 75–84.

[16] Lyubenova M., Dimitrova V., Chemical Elements in Mulch and Litterfall of Beech Ecosystems and Their Total Turnover. *Ecologia Balcanica*, ISSN 1314-0213, V. 3(1), 2011, pp. 51-57.

[17] Dimitrova V., Damyanova S. Litterfall in common beech (*Fagus sylvatica* L.) forest communities – a depot of important chemical elements. *Scientific studies of the Union of Scientists, Plovdiv. Series B: Natural Sciences and Humanities*, ISSN: 1311-9192, eISSN: 2534-9376, V.18, 2018, pp. 59-63.

[18] Dimitrova V., Dimitrov D., Malchev D. Litterfall in beech (*Fagus sylvatica* L.) forests. *Proc. of Vth International Halich Congress of Multidisciplinary Scientific Research*, 15-16.01.23, Turkey, M. Eliacik (Ed.), Iksad Publishing House, 2023, pp.702-706.

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

-Violeta Dimitrova carried out the calculation and representation of the results.

-Sonya Damianova organized and executed the experiments.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

The studies were funded by the project: "Structure and ecological functions of dead biomass in beech forests (*Fagus sylvatica* L.) in Western Bulgaria", КР – 06-H54/1, 2021, Ministry of Education and Science, Scientific Researches Fund.

Conflict of Interest

The authors have no conflict of interest to declare.