

Assessment of aboveground litterfall under the beech forest canopy in Vitinya permanent sample plot

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Abstract

Aboveground litterfall plays a key role in carbon and nutrient cycling in forest ecosystems. In this study, data are obtained about basic aboveground litterfall parameters and quantity of common beech (*Fagus sylvatica* L.) in Vitinya permanent sample plot for intensive monitoring. The litterfall was sampled and assessed in three individual fractions – foliar fraction (*F*), wood fraction (*W*) and fruits and seeds fraction (*FS*). It was established that annual total biomass of aboveground litterfall varies in wide range from 390 up to 787 g·m⁻². The most dynamic fluctuations in the quantity are found in the *F* fraction of total biomass that falls annually on the soil surface. For 2022, the average amount of *F* fraction was 363 g·m⁻², which represents 59 % of the total biomass of litterfall. The reaction of litterfall in the studied fractions for the observed period remains in the acidic spectrum. In the individual fraction's concentrations of basic cations, such as calcium and magnesium, are assessed as low. The obtained data show increasing trend of trace elements, such as iron, manganese, copper, and cadmium in *F* fraction. Very high concentrations of manganese and cadmium were found in all fractions of the aboveground litterfall. For manganese the average value in *F* fraction was 4373 µg·g⁻¹ and for cadmium in *FS* fraction – 388 ng·g⁻¹. Both obtained concentrations exceed the upper limit of these elements specified in the ICP Forests Manual for common beech litterfall fractions.

Key words: beech litterfall, intensive monitoring, litterfall fractions, litterfall pH, nutrients, trace elements.

Introduction

Litterfall is a key parameter linking trees to water transfer and soils in the biogeochemical cycle of terrestrial ecosystems (Pitman 2013, ICP Forests Manual 2020). The aboveground litterfall introduces most of soil organic carbon content into the soil (Sayer 2006), which allows forecasting the retention of org. C in the soils (Liski

et al. 2005). According to Schleppi et al. (2007), the total mass and chemical composition of the litterfall are important for assessing the nutrients in forest soils. The magnitude of litterfall production is a crucial estimate for predicting the terrestrial carbon budget (Li et al. 2019).

Litterfall in forest ecosystems is the most important resource of soil organic matter and soil nutrients (Gairola et al.

2009) and therefore its quantity maintains the soil fertility (Meier et al. 2005, Zhang et al. 2014). It is estimated that in forests, litterfall can introduce approximately 18 Pg C per year to the soil surface. That amount of org. C is about one-third of the annual C uptake (Zhao and Running 2010, Malhi et al. 2011). The quality and quantity of litterfall production in temperate forests significantly affect the carbon and nutrient cycling (Xu et al. 2004, Roig et al. 2005, Neumann et al. 2018). Litter decomposition rate can determine the amount of organic matter input to forest soils (Vesterdal et al. 2008). In addition, soil's physical and chemical properties, microbial activity and diversity of soil microorganisms are directly and indirectly influenced by the litterfall (Wang et al. 2008, Farooq et al. 2022).

Long-term observations on aboveground litterfall can help to understand its impact on different ecosystem processes and how forest tree species are adapting to these changes. (Bhatti and Jassal 2014). The annual quantification of the different litter fractions can indicate the stand reaction to short and long-term weather fluxes (Broadmeadow 2002). Assessing aboveground litterfall and its basic parameters can help in modelling and predicting terrestrial ecosystem dynamics (Liski et al. 2005). It is important to note that for deciduous species, litterfall collection throughout one year and sorting it is probably the most accurate way of measuring total leaf area produced (Bréda 2003).

One of the world's largest biomonitoring networks, which provide information on forest condition, air pollution, climate change and biodiversity over the last 30 years, is International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (also known as ICP Forests). The observations

of forest conditions are carried out on 2 levels. Level I (large-scale representative monitoring on a systematic network) aim to provide a periodic overview of the spatial and temporal variation of forest condition in relation to anthropogenic and natural stress factors (in particular air pollution). Level II (intensive monitoring on a number of selected permanent observation plots) aim to gain a better understanding of the cause-effect relationships between the condition of forest ecosystems and anthropogenic, as well as natural stress factors (in particular air pollution).

In Bulgaria, as part of the European Forest Ecosystem Monitoring Network, the parameters of aboveground litterfall and soil solution sampled by tension lysimeters are measured at 3 permanent sample plots (Level II) for intensive monitoring – 'Vitinya', 'Yundola' and 'Staro Oryahovo' (Kolarov et al. 1999–2002, Malinova et al. 2003). The surveys on intensive monitoring in the country until 2019 are carried out in accordance with instructions of ICP Forests (1986–2016). Since 2020 update in Part XIII Sampling and Analysis of Litterfall, new rules are applied in assessing the aboveground litterfall (ICP Forests Manual 2020).

The aim of the study is to quantify aboveground litterfall production by fractions and its chemical composition in Vitinya permanent sample plot for intensive monitoring of common beech (*Fagus sylvatica* L.) forest ecosystems. The basic parameters of litterfall and their annual dynamics were observed and assessed for the period 2011–2022.

Subject and Method

Vitinya permanent sample plot is set in the Western Balkan Range, on the terri-

tory of Vitinya State Hunting Enterprise (42°46'12" N and 23°45'36" E). The permanent sample plot is located in the middle mountain subarea (Koleva-Lizama 2002), which is characterized by a mountain climate.

It was selected as representative for the common beech forests in Bulgaria (Kolarov et al. 2002) at an altitude 1145 m a.s.l. The soil is developed on metamorphic bedrock – gneiss. It is well-known fact that gneiss tends to lead to acidic, poorly developed soils and the soil unit in Vitinya permanent sample plot area is classified as *Dystric Cambisols*.

Aboveground litterfall was collected in 5 traps, set under the beech forest canopy, each with an area of 1 m². The biomass in the litterfall traps was collected every two weeks. The litterfall was sorted into three different fractions – foliar fraction (*F*), wood fraction (*W*) composed of bark, branches and twigs and fruits and seeds fraction (*FS*).

Sampling and laboratory analyses of the observed parameters were carried out by the Executive Agency for the Environment at the Bulgarian Ministry of

Environment and Waters. The survey of aboveground litterfall is carried out in connection with the implementation of 'The International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests under the Convention on Long-range Transboundary Air Pollution of the United Nations Economic Commission for Europe' (Level II).

The obtained data in Vitinya permanent sample plot are compared to the indicated minimum and maximum values for the different parameters of litterfall according to ICP Forests Manual (2020).

Results and Discussion

The aboveground litterfall in the forest ecosystems is composed mainly of different amounts of foliage, branches, bark and reproductive organs. Usually, foliage litterfall occupies a major fraction of total litterfall (Liu et al. 2003). In Vitinya permanent sample plot for intensive monitoring of *Fagus sylvatica* ecosystem the total mass of aboveground litterfall has been observed for the period 2011–2022 (Fig. 1). The re-

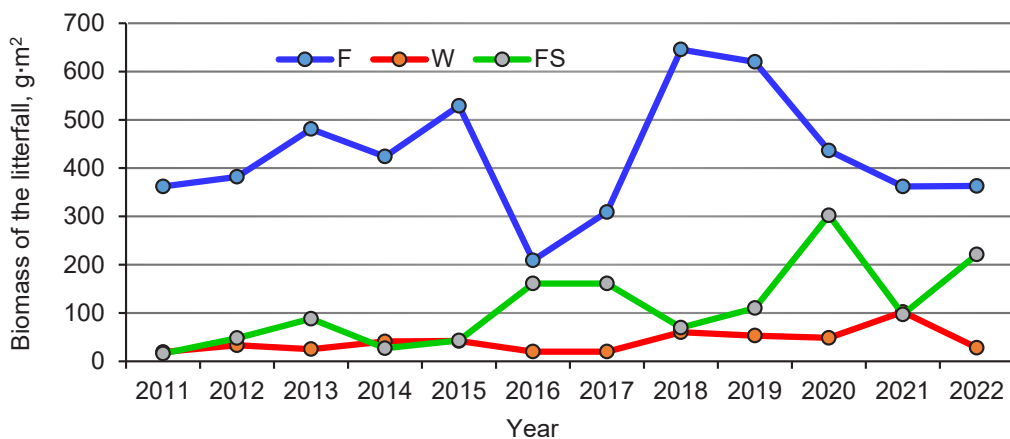


Fig. 1. Biomass of the aboveground litterfall by fractions for the period 2011–2022.

Note: *F* – foliar fraction, *W* – wood fraction, *FS* – fruits and seeds.

sults showed that annual total biomass of aboveground litterfall varies widely between 390 and 787 g·m⁻². The quantity of the individual aboveground litterfall fractions determines the annual dynamics of the total biomass.

In Vitinya permanent sample plot the annual foliar fraction of the aboveground litterfall comprised 54–91 % of the total biomass of the litterfall. This considerable variation in the percentage content of the foliar fraction of the total amount of litterfall could be explained by microclimatic conditions in the stand. Park et al. (2020) pointed out a narrower range of variation in deciduous stands for foliar fraction, which comprised 60 % up to 69 % of the total litterfall, while Petritan et al. (2020) reported that 66 % of the litterfall was composed of beech leaves. Fruit and seeds fraction (*FS*) also varies considerably between 4 % and 41 % of the total biomass of the litterfall that fall into the litter traps every year. The amount of wood fraction (*W*) varies within narrower limits (4–18 %) depending on the season and was the least abundant in the litterfall. The maxima of aboveground litterfall for the deciduous trees varies in wide range according to tree species from early fall to early winter. For *Fagus sylvatica* the main peaks are due to leaf fall and usually occur in October or November (Bou et al. 2015). In 2022, for Vitinya permanent sample plot the maximum of total biomass of litterfall and foliar fraction was recorded within 1 month. It was in October, in contrast to the previous two years, when the maximum was recorded in November. Fractions *W* and *FS* are traditionally poorly represented in the total biomass of the litterfall. Regarding their distribution by months, these fractions have more significant amounts in the late spring and autumn.

The data show that wood fraction

was in high amounts at the beginning of the vegetation season – April and in the end – September. The largest amount of fruits and seeds fraction was established in September–October.

Table 1 presents the chemical characteristics of the aboveground litterfall by fractions in 2022.

The data in Table 1 show that pH_{H2O} by fractions for 2022 remain in strongly acidic spectrum. In general, it should be noted that the pH values indicate stability (Fig. 2) over time. The pH of *F* fraction changes very slightly. For this fraction, similar values were obtained in 2022 but lower than in the previous years. The reaction is more acidic compared to the one in 2021. The same applies to the *FS* fraction. In 2019, the lowest pH values for *FS* fraction were obtained, but it should be considered as random event. For *W*, the values are higher compared to 2021. For this fraction, high average values were obtained in 2016 and 2017, which can be accepted as accidental.

The reaction of the *FS* fraction showed a wider range of variation but is in the acidic spectrum throughout the observed period.

In 2022, the nitrogen content in the *F* fraction is assessed as low and close to the minimum values specified in the ICP Forests Manual (2020) for common beech litterfall (Table 1). For the period 2011–2022, it varies within the limits of the minimum and maximum values specified in manual and this is an indicator of good nitrogen uptake. The same applies to the amount of sulphur, which are low in all three fractions.

The nitrogen content of the aboveground litterfall for 2022 was assessed as average – it was in the range between the lower and upper limits specified in the manual for common beech lit-

Table 1. Concentrations of macronutrients and trace elements in aboveground litterfall from Vitinya permanent sample plot – 2022.

Litter traps No	Fraction	$\text{pH}_{\text{H}_2\text{O}}$	Org. C, g per 100g	mg·g ⁻¹							μg·g ⁻¹				Cd ng·g ⁻¹
				N	S	P	Ca	Mg	K	Zn	Mn	Fe	Cu	Pb	
1	Foliar fraction	5.1	52.6	9.3	0.8	0.4	7.3	0.9	6.0	47	4643	200	9.4	1.6	<30
2		5.0	52.0	10.0	0.8	0.5	4.0	1.0	6.4	26	4143	207	10.8	1.6	215
3		5.1	52.2	9.3	0.8	0.5	4.0	0.9	5.4	27	4087	172	10.8	1.4	219
4		5.1	54.2	9.7	1.2	0.5	4.3	1.1	5.8	35	4574	198	10.8	1.4	215
5		5.0	51.9	10.4	1.0	0.6	4.2	1.0	4.7	38	4419	229	10.1	1.7	216
Mean	Wood fraction	5.1	52.6	9.8	0.9	0.5	4.7	1.0	5.6	35	4373	201	10.4	1.6	216
St. dev.		0.1	1.0	0.5	0.2	0.1	1.4	0.1	0.6	9	250	20	0.7	0.1	1.8
1		5.5	53.5	13.8	0.9	1.2	<3.0	0.9	8.8	2	1413	91	16.7	10.5	106
2		5.4	53.1	8.9	0.9	0.9	<3.0	0.7	8.1	8	1204	95	10.7	0.7	108
3		5.6	53.6	12.4	0.8	1.0	<3.0	1.0	8.4	20	1564	106	13.8	1.3	108
4	Fruits and seeds	5.5	55.2	13.7	0.9	1.3	<3.0	1.1	9.0	23	1644	121	13.9	0.6	107
5		5.3	52.7	9.2	0.8	0.9	<3.0	0.7	8.4	14	1251	104	10.7	0.8	108
Mean		5.5	53.6	11.6	0.9	1.1		0.9	8.5	13	1415	103	13.1	2.8	107
St. dev.		0.1	0.9	2.4	0.0	0.2		0.2	0.4	9	191	12	2.5	4.3	0.8
1	Foliar fraction	5.2	55.3	6.1	0.8	0.2	7.2	0.4	2.1	60	1288	120	15.3	4.3	321
2		5.3	54.5	9.1	0.8	0.5	9.6	0.5	1.9	62	1661	218	20.7	6.5	432
3		5.3	54.3	8.7	0.8	0.5	7.0	0.4	1.8	40	1207	165	16.6	5.4	324
4		5.2	54.3	8.4	1.2	0.5	9.2	0.5	1.9	59	1375	195	18.5	7.7	432
5		5.2	55.5	7.8	0.9	0.3	8.0	0.4	1.5	111	1307	252	18.1	6.3	429
Mean	Foliar fraction	5.2	54.8	8.0	0.9	0.4	8.2	0.4	1.8	66	1367	190	17.9	6.0	388
St. dev.		0.1	0.6	1.2	0.2	0.1	1.1	0.1	0.2	26	174	51	2.0	1.3	59

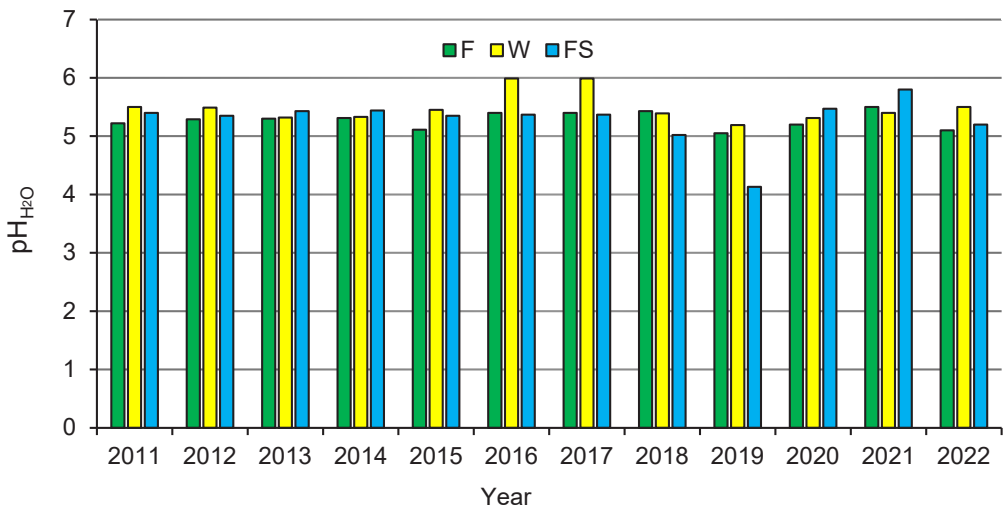


Fig. 2. Reaction ($\text{pH}_{\text{H}_2\text{O}}$) of the aboveground litterfall fractions for the period of 2011–2022.
Note: *F* – foliar fraction, *W* – wood fraction, *FS* – fruits and seeds.

terfall (Table 1). Its quantity differs in the individual fractions throughout the study period (Fig. 3). It should be noted that most significantly total nitrogen differs in *FS* fraction, followed by *F* fraction and most stable it is in *W*.

The mean org. C/N ratio also differed in wide range in the studied fractions.

The highest mean value was obtained in *W* – 70, which corresponds to the slow decomposition of organic matter. It was also high in fraction *F* – 52. *FS* fraction was with the fastest decomposition rate – org. C/N = 48.

Due to increased air pollution in the late 20th century, the sulphur concentra-

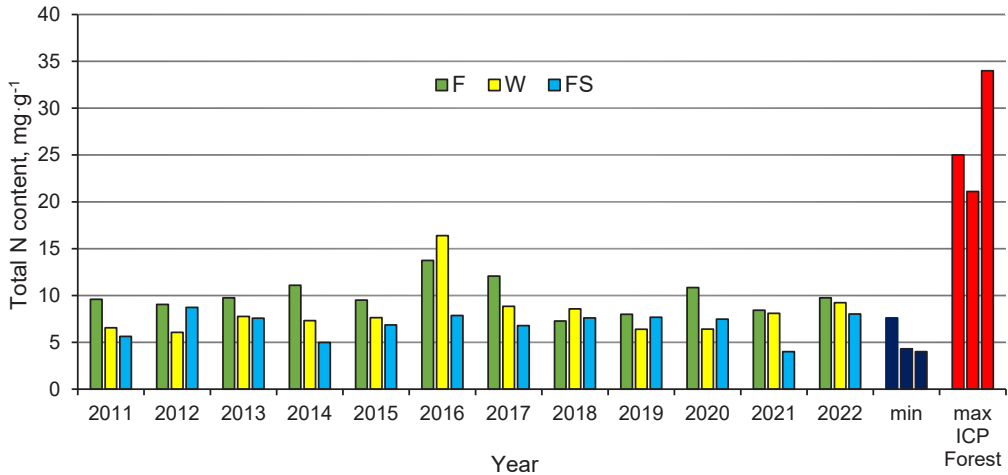


Fig. 3. Total nitrogen content in aboveground litterfall fractions for the period of 2011–2022 and ICP Forests criteria.
Note: *F* – foliar fraction, *W* – wood fraction, *FS* – fruits and seeds.

tions in deciduous litterfall are monitored in the forest monitoring system.

According to several authors (Koptsik et al. 1998, Michel and Seidling 2017), the high concentrations of sulphur in the litterfall are associated with more intensive acidic atmospheric depositions.

The obtained data showed that the sulphur concentration in the aboveground lit-

terfall from Vitinya permanent sample plot for the observed period was between the minimum and maximum limits (Fig. 4). A decreasing trend of sulphur concentrations in *F* fraction is observed since 2011. The obtained data for 2022 (Table 1) shows that sulphur concentrations are low and very close to the minimum concentrations specified in the ICP Forests Manual (2020).

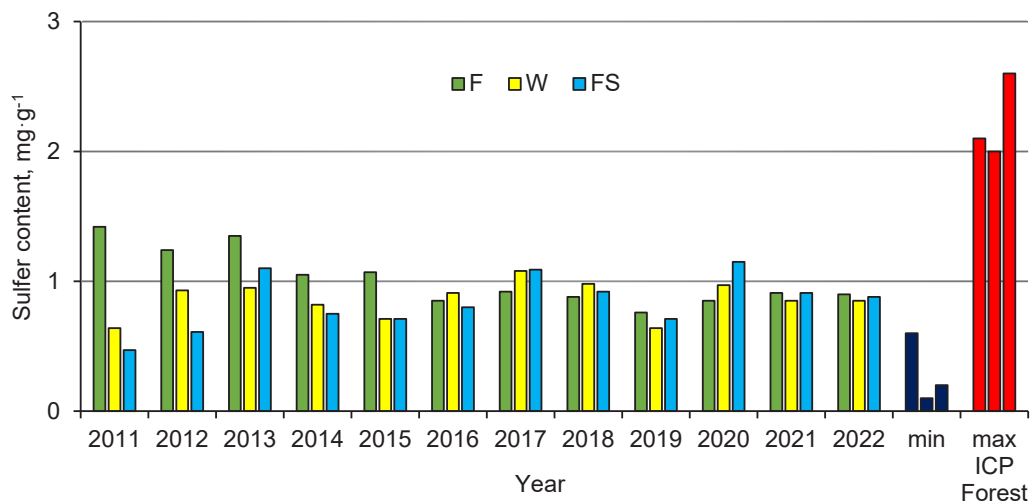


Fig. 4. Sulphur concentration in aboveground litterfall fractions for the period of 2011–2022 and ICP Forests criteria.

Note: *F* – foliar fraction, *W* – wood fraction, *FS* – fruits and seeds.

The quantity of macronutrients in litterfall play a crucial role in their re-entry on the soil surface. The content of phosphorus and calcium in *F* fraction is low, as in the previous 3 years, with values close to the minimum. They vary slightly around the lower limit for these elements. In *W*, phosphorus and calcium are even in lower concentrations – for phosphorus they vary around 1.0, and for calcium – below the limit of determination of the method (less than 3.0 mg·g⁻¹). The results obtained in 2022 confirm that calcium shows a clear tendency to accumulate in the *FS* fraction. In all studied fractions the concentrations

of magnesium are assessed as low. It should be noted that potassium concentrations vary widely from low to high. The low amounts of the main macro elements, such as calcium and magnesium in the litterfall is a prerequisite for low amounts in the mineral part of the soil as well. That can lead to more intensive process of soil impoverishment.

As for the trace elements, such as iron, manganese, copper and cadmium, the negative trend from previous years is maintained - their concentrations have increased in the *F* fraction. This is most pronounced for the more mobile elements,

especially for manganese, which has very high values in *F* fraction, exceeding the maximum values. The concentration of cadmium in the *F* and *W* fractions is very high. The accumulation of cadmium in the *FS* fraction exceeds the indicated upper limit of concentration for this element. Copper concentrations are high in *F* and *W* fractions. It should be noted that *FS* fraction accumulates very high concentrations of copper and lead. Their values are close to the maximum specified in ICP Forests Manual (2020). The accumulation of trace elements in *W* and *FS* fractions of the beech litterfall indicates their increased concentration and mobility in the soil solution, as well.

Conclusions

In 2022, the reaction of the aboveground litterfall in the individual fractions remain in the acidic spectrum. For the observed period it should be noted that the concentrations of phosphorus and calcium remain low. Higher uptake and accumulation of trace elements with acidic functions in the aboveground litterfall and the higher acidity obtained in all fractions indicate ongoing acidification process of the soil solution and vice versa. The decreasing trend of sulphur concentrations in foliar fraction continues. More concern are the higher concentrations of manganese in *F* fraction and cadmium in *FS* fraction, which exceeds the maximum values specified in the ICP Forests Manual (2020). To determine whether there is a contamination with these heavy metals, their concentrations must also be traced in the soil depth.

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