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Dynamics, structure and properties of plant litterfall in a 120-year old beech stand in Middle Pomerania between 2007–2010

Abstract: Studies of plant litterfall mass, its dynamics, structure and chemical composition were conducted between 2007–2010 in a 120-year old beech (*Fagus sylvatica* L.) stand located in Middle Pomerania. The annual mass of litterfall during the study period ranged from 2.793 to 5.398 t·ha^{-1} and its maximum was observed during the seed year. Leaves were the major component of plant litterfall and their contribution was 82.4–84.5% in the non-seed years and 47.2% during the seed year. Inflorescences, seeds, and seed coats were important components of litterfall during the seed year and accounted together up to 39.8% of the total litterfall mass. Particular fractions of litterfall significantly differed in the chemical composition. The highest concentrations of nitrogen, phosphorus and potassium were noticed in seeds and leaves collected in spring and the maximum content of calcium was observed in leaves collected in autumn. The weighted mean annual concentrations of nitrogen ranged within 0.81–1.13%, phosphate – 0.126–0.153%, potassium – 0.298–0.485% and calcium – 0.416–0.583%. The influx of elements with litterfall to the soil was: 167.3–225.9 kg·ha^{-1} of ash, 23.2–61.0 kg·ha^{-1} of nitrogen, 3.6–7.6 kg·ha^{-1} of phosphorus, 8.3–26.2 kg·ha^{-1} of potassium and 15.3–22.4 kg·ha^{-1} of calcium.

Key words: plant litterfall, *Fagus sylvatica* L., nutrient cycling, Middle Pomerania

INTRODUCTION

Common beech (*Fagus sylvatica* L.) is a tree species naturally occurring in the Pomerania area. In the XVII–XIX centuries it was superseded from many sites in effect of forest management and replaced mainly by pine and spruce and rarer also larch stands. Its restitution followed by the gradual disappearance of coniferous species that at present occur only as admixtures in the old-growth forest has been observed for over 50 years. There are many varying opinions on the role of beech, the main component of forest ecosystems, on the properties and functioning of soils, particularly in regard to its influence on the intensity podzolization processes. Studies carried out in the early 1930-ties (Chodzicki, 1934) on the influence of beech admixtures in pine forests on soil properties indicate that the species may variably interact on various soil types. The admixture of beech on podzols caused reduction of their acidity, whereas when grown on cambisols the acidity increased. According to these studies, beech as a species with high iron demands (in comparison to pine and spruce), favours its immobilization in the topsoil, restricting the intensity of podzolization. Similarly, in the opinion of Augusto et al. (2002), beech has smaller influence on soil podzolization in comparison to most coniferous species in Europe. Comparative studies of lysimetric waters from organic and humic horizons of Dystric Arenosols under beech and beech-pine stands carried out in Middle Pomerania have indicated that higher acidification was observed within pure beech stands with pine admixture. Higher concentrations of dissolved organic carbon, iron and aluminium were observed in mixed stands, pointing to the larger intensity of podzolization processes (Jonczak, 2012). Many studies supply evidence that in comparison to other European deciduous species, beech causes strong soil acidification, particularly in the topsoil (Hägen-Thorn et al., 2004; Barbier et al., 2008). Acidification is caused by less intense circulation of alkaline components in the beech stands, which is the result of a lower decomposition rate of beech litterfall that contains relatively low amounts of nitrogen.

Conclusions on the influence of beech on soil properties based on the analysis of their properties may be, however, biased, because contemporary soils have developed under past plant communities, whose reconstruction is rather impossible. Comparisons are reliable only for organic and humus horizons of the soil profile, whose properties change relatively fast under the influence of plants. Analysis of the chemi-

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cal properties of throughfall and water flowing stemfloow (Brown and Sposito, 1991; Christ and David, 1996; Janek, 2000; Kaiser et al., 2002; Kowalkowski et al., 2002; Jóźwiak and Kozłowski, 2004; Remeš and Kulhavý, 2009) as well as the quantitative and qualitative features of litterfall (Norden, 1994; Dziadowiec and Kaczmarek, 1997; Nilsson et al., 1999; Jonczak et al., 2010; Jonczak, 2011) can be a good indicator for the assessment of the influence of various tree species on soils. Transformation of the chemical composition and production of litterfall belong to the main mechanisms of plant influence as a pedogenic factor. A systematic, long-term influx of throughfall and litterfall with properties specific for particular tree species may cause intense and deep changes of the soil chemical composition, generate or intensify the soil processes and during longer periods – influence the course of pedogenic processes.

The studies were focused on determining the mass, structure, dynamics and chemical composition of litterfall and assessing the influx of litterfall with selected elements to soil in a 120-year old beech stand in Middle Pomerania between 2007–2010.

MATERIAL AND METHODS

Studies of litterfall were conducted in the Łysomice Forest District (Leśny Dwór Forest Inspectorate, Regional Directorate of State Forests in Szczecinek) between 2007–2010. The study area (40×40 m in size) was selected in Plant no. 148a within a fragment of a 120-year old beech forest stand with a few 90-year old individuals. Tree density in the study area was 175 trees/ha, with heights of 25–29 m and breast height diameter 16.7–79.3 cm (averagely 43.3 cm). According to the valuation description, the trees were assigned to the II quality class. The studied area was located within a mixed fresh forest.

Studies of litterfall were carried out with application of 16 round traps, 50 cm in diameter, installed 1 m above ground level and regularly distributed within the study area. Litterfall was collected once a month, dried to solid mass at 65°C, sub-divided into fractions and weighed. The following fractions were distinguished: leaves, branches, inflorescences, seed coats, seeds, and other components (bark and small, unrecognizable organic fragments). Leaves and other fragments were further sub-divided into fractions with regard to the collection season. Particular fractions of litterfall were homogenized and their chemical composition was determined. The ash content was determined by the ignition loss method at 450°C, the content of total organic carbon (TOC) – by the Alten method, total nitrogen (TN) – by the Kjeldahl method (with application of VELP UDK 127 distiller), as well as phosphorus, potassium and calcium in the solution after mineralization in an acid mixture (HNO_3, $HClO_4$ and H_2SO_4 at 20:5:1). The phosphorus content was determined colorometrically by the molibdate method (spectrophotometer UV-VIS RAILEIGH UV-1800), and potassium and calcium – by flame emission spectroscopy (photometer SHERWOOD 410). All analyses were made in two replication. Statistic analysis of the results was made using EXCEL software.

A soil pit was made in the central part of the study area; the soil profile was described and samples were collected from each genetic horizon for laboratory analysis. The following properties were determined: grain size composition (combination of sieve and pipette methods; division into fractions and textural groups according to PTG 2008), reaction (potentiometer method), total organic carbon (TOC) content (Tiurin method in samples from mineral horizons and Alten method in samples from organic horizons), total nitrogen content (TN) (Kjeldahl method), total content of phosphorus, potassium and calcium in solutions after mineralization in the mixture of HNO_3, $HClO_4$ and H_2SO_4 for organic samples and in the mixture of HF and $HClO_4$ for mineral samples. Concentrations of elements in the solutions were determined using the same methods as for litterfall.

The study area was covered by Brunic Arenosols developed from Quaternary sands with interbeddings of loam in the parent rock horizon. The soils contained fresh moder humus. Soil reaction was strongly acidic – pH_{H2O} was within 4.34–5.01 in the organic horizons and 3.77–4.98 in the mineral horizons. The soils contain low amounts of nitrogen, phosphorus and alkaline components – potassium and calcium (Table 1).

RESULTS AND DISCUSSION

Litterfall Mass, Dynamics And Structure

Litterfall in forest ecosystems is a mixture of leaves, branches, generative organs and other remains from trees, bushes and groundcover. The mass of organic remains that are annually introduced to the soil depends on a number of environmental factors, e.g. their taxonomic composition, age, density and condition (Owington, 1959; Bray and Gorham, 1964; Stachurski and Zimka, 1975; Bell, 1978; Dziadowiec and Plichta, 1985; Dziadowiec and Kaczmarek, 1997; Prescott et al., 1999; Dziadowiec et al., 2007; 2008; Parzych and Trojanowski, 2009; Jonczak, 2011). In the studied forest stand, the influx of litterfall varied in

TABLE 1. Selected properties of soils

Horizon	Depth [cm]	Textural group PTG 2008	pH		TOC	TN	P	K	Ca
			H_2O	KCl	%				
Ol	4–2	–	5.01	4.33	52.56	0.948	0.085	0.104	0.614
Ofh	2–0	–	4.34	3.59	44.57	1.566	0.103	0.147	0.424
AEs	0–5	sand	3.77	2.93	3.77	0.194	0.029	1.039	0.282
Bhs	5–9	sand	3.90	3.22	1.58	0.083	0.040	1.005	0.269
BhsBv	9–31	sand	4.50	4.04	0.66	0.038	0.033	1.107	0.334
C1	31–61	sandy loam	4.70	3.85	–	–	0.031	1.589	0.370
C2	61–86	sandy loam	4.73	3.74	–	–	0.040	1.591	0.432
C3	86–140	loamy sand	4.98	3.90	–	–	0.023	1.382	0.350

TABLE 2. Mass of plant litterfall fractions [$t \cdot ha^{-1}$] and its percentage in the total mass of litterfall [%] between 2007–2010 (mean ± SD; n=16).

Litterfall fractions		2007	2008	2009	2010
Leaves	$t \cdot ha^{-1}$	2.300 ± 0.256	3.205 ± 0.540	2.547 ± 0.303	3.095 ± 0.328
	%	82.4	82.8	47.2	84.5
Branches	$t \cdot ha^{-1}$	0.195 ± 0.185	0.348 ± 0.349	0.321 ± 0.349	0.134 ± 0.160
	%	7.0	9.0	5.9	3.7
Inflorescences	$t \cdot ha^{-1}$	0.000	0.000	0.322 ± 0.079	0.000
	%	0.0	0.0	6.0	0.0
Seeds	$t \cdot ha^{-1}$	0.000	0.000	0.688 ± 0.224	0.000
	%	0.0	0.0	12.8	0.0
Seed coats	$t \cdot ha^{-1}$	0.000	0.000	1.133 ± 0.511	0.121 ± 0.104
	%	0.0	0.0	21.0	3.3
Others	$t \cdot ha^{-1}$	0.297 ± 0.126	0.318 ± 0.053	0.388 ± 0.053	0.313 ± 0.121
	%	10.6	8.2	7.2	8.5
Sum of all fractions	$t \cdot ha^{-1}$	2.793 ± 0.307	3.871 ± 0.638	5.398 ± 0.891	3.663 ± 0.475
Litterfall mas per tree	kg	15.96	22.12	30.85	20.93

the subsequent years within 2.793–5.398 $t \cdot ha^{-1}$ (Table 2). The observed values are typical of Polish forest ecosystems (Stachurski and Zimka, 1975; Dziadowiec and Kaczmarek, 1997; Małek, 2006; Dziadowiec et al., 2007; Kowalkowski and Jóźwiak, 2007; Parzych and Trojanowski, 2009; Niewinna, 2010; Jonczak, 2011). Litterfall influx to the soil had an annual dynamics characteristic of temperate forests with a major autumn maximum linked with litterfall and a minor spring maximum caused by fall of seed coats, and inflorescences – in the seed year (Fig.). The dominating fraction of litterfall in all the studied years were leaves, which comprised 82.4–84.5% of the total mass in the non-seed years and 47.2% in the seed year (Table 2). The contribution of branches was at the level of 3.7–9.0% and of other fragments – 7.2–10.6%. In 2009, a large contribution in the litterfall had beech seed coats (21.0%), seeds (12.8%) and inflorescences (6.0%). Generative parts in the seed year comprised up to 39.8% of total litterfall. The production of litterfall per tree reached 15.96, 22.12, 30.85, and 20.93 kg in the subsequent years.

Chemical composition of litterfall

The chemical composition of litterfall is a resultant of the taxonomic features of plants and widely understood properties of the stand, particularly its abundance in biogenes and reaction. The content of ash particles in the studied litterfall was within 5.3–6.4%. Concentration of nitrogen was at the level of 0.81–1.13%; phosphorus – 0.126–0.153%; potassium – 0.298–0.485% and calcium – 0.416–0.583% (Table 3). The annual weighted means TOC/TN were at 46:1–64:1 and TOC/P – at 379:1–454:1. A distinct variability of the chemical composition of particular fractions of litterfall was observed. The largest contribution of the ash particles was observed in leaves from the autumn litterfall maximum (6.5–7.6%) and other fragments collected in autumn (4.6–7.8%), whereas the smallest – in inflorescences (1.9%), branches (2.4–3.4%) and other fragments from spring litterfall (2.5–2.7%). The richest in nitrogen were beech seeds (2.54%), leaves from spring litterfall (1.53–1.99%) and other fragments collected in autumn and winter – up to

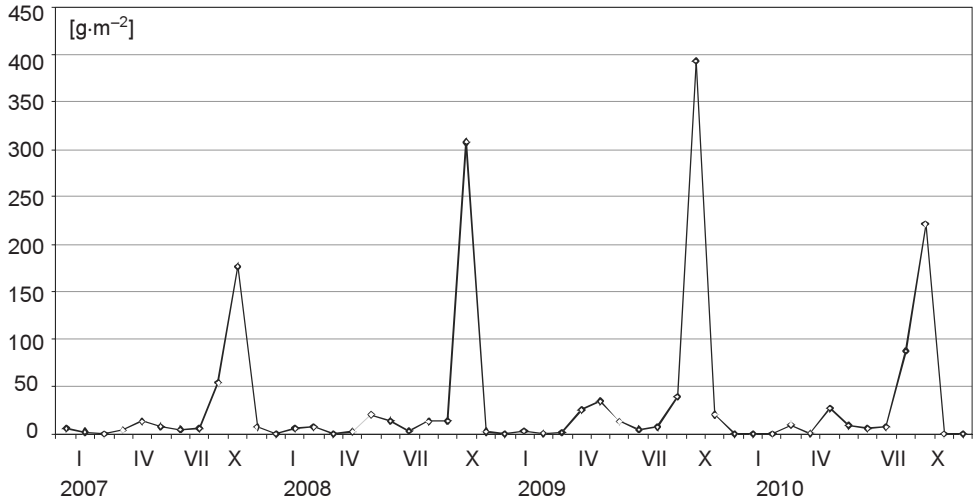

FIGURE. Dynamics of plant litterfall between 2007–2010

TABLE 3. Chemical composition of plant litterfall between 2007–2010

Litterfall component	Ash	TOC	TN	P	K	Ca	TOC/TN	TOC/P
	%							
2007								
Leaves spring	3.8	48.3	1.87	0.133	0.530	0.344	26	362
Leaves summer	5.7	49.0	1.56	0.126	0.425	0.369	31	390
Leaves autumn	7.6	46.8	1.03	0.186	0.309	0.697	45	251
Branches	2.4	51.1	0.63	0.052	0.136	0.378	81	985
Others spring	2.7	47.8	0.98	0.069	0.085	0.345	49	689
Others summer	4.3	46.9	1.71	0.117	0.218	0.430	27	399
Others autumn	4.6	50.1	0.75	0.046	0.065	0.680	67	1090
Annual mean*	**6.4**	**47.6**	**1.11**	**0.153**	**0.298**	**0.583**	**46**	**379**
2008								
Laves spring	4.0	48.2	1.90	0.138	0.470	0.338	25	349
Laves summer	6.0	48.5	1.64	0.125	0.418	0.367	30	387
Laves autumn	6.5	49.1	0.75	0.141	0.467	0.579	65	347
Banches	2.5	51.7	0.61	0.050	0.126	0.361	86	1038
Others spring	4.1	48.7	1.36	0.095	0.116	0.527	36	513
Others spring	2.6	46.8	0.73	0.046	0.109	0.379	64	1017
Others summer	5.3	47.5	1.67	0.118	0.229	0.421	29	403
Others autumn	5.3	50.2	1.64	0.160	0.279	0.449	31	313
Annual mean*	**5.8**	**49.1**	**0.81**	**0.126**	**0.407**	**0.532**	**64**	**454**
2009								
Leaves spring	3.7	48.6	1.99	0.140	0.503	0.347	24	347
Leaves summer	6.4	48.4	1.42	0.140	0.620	0.417	34	345
Laves autumn	7.0	48.5	1.05	0.164	0.477	0.619	46	297
Branches	2.7	49.2	0.71	0.048	0.136	0.381	70	1031
Inflorescences	1.9	46.2	1.45	0.074	0.119	0.249	32	620
Seeds	6.4	57.5	2.54	0.294	0.695	0.346	23	196
Seed coats	3.6	44.1	0.38	0.072	0.632	0.141	116	610
Others winter	5.9	47.1	1.96	0.132	0.136	0.335	24	357
Others spring	2.6	45.1	0.78	0.066	0.233	0.341	58	685
Others summer	3.1	42.7	0.84	0.054	0.142	0.471	51	785
Others autumn	6.9	45.7	1.84	0.167	0.328	0.481	25	273
Annual mean*	**5.3**	**48.4**	**1.13**	**0.141**	**0.485**	**0.416**	**58**	**439**
2010								
Leaves spring	1.4	44.4	1.53	0.168	0.404	0.461	29	265
Leaves summer	5.5	46.6	1.24	0.128	0.420	0.437	38	365
Leaves autumn	7.4	44.7	0.99	0.169	0.440	0.634	45	264
Branches	3.4	48.0	0.70	0.045	0.099	0.463	69	1056
Seed coats	1.8	44.8	0.24	0.023	0.143	0.139	187	1913
Others spring	2.5	45.6	0.86	0.061	0.139	0.341	53	751
Others summer	7.8	45.3	1.80	0.143	0.258	0.367	25	316
Annual mean	**6.2**	**45.3**	**1.01**	**0.141**	**0.388**	**0.538**	**49**	**410**

* weighted means by mass of particular fractions of litterfall.

1.96%. In turn, the lowest concentrations of this element were noted in beech seed coats (0.38) and branches (0.61–0.71%). In leaves collected in autumn, which were the main contributor of the litterfall mass in subsequent years, the nitrogen content was at the level of 0.75–1.05%. In comparison to other deciduous trees, beech litterfall was poor in nitrogen.

In the studied forest stand, litterfall was moderately rich in phosphorus, taking into account the low concentration of this element in the soil (Table 1). The content of phosphorus in leaves from autumn litterfall was from 0.141 to 0.186% in subsequent years (Table 3). The fraction with the largest content of phosphorus were beech seeds (0.294%), whereas the minimal amounts were observed in seed coats (0.023%), branches (0.045–0.052%) and other fragments from spring litterfall (0.046–0.069%).

The concentration of potassium in leaves from the autumn maximum was in subsequent years at the level of 0.309–0.477%, in branches – 0.099–0.136%, and in other fragments – 0.085–0.328%. Inflorescences contained 0.119% potassium, seeds – 0.695%, and seed coats – 0.632% (Table 3). Leaves from autumn litterfall and other fragments from this interval contained the largest amounts of calcium (0.579–0.697% and 0.481–0.680%, respectively), whereas the smallest amounts of calcium were noted in beech seed coats (0.141%).

Influx of elements to the soil with litterfall

The mass of litterfall fractions and their chemical composition control the amount of particular elements that are introduced to soil during the entire year. The influx of ash particles in the studied forest stand in subsequent years was 167.3–225.9 kg·ha^{-1}, nitrogen – 23.2–61.0 kg·ha^{-1}, phosphorus – 3.6–7.6 kg·ha^{-1}, potassium – 8.3–26.2 kg·ha^{-1} and calcium – 15.3–22.4 kg·ha^{-1} (Table 4). The largest influx of all components to the soil was noted in the seed year, which is the result of the highest mass of litterfall in this interval and large abundance of the analyzed elements in the generative organs in comparison to other fractions. In the non-seed years the influx of nitrogen, potassium and calcium with litterfall to the soil was low in comparison to other Polish forest stands (Dziadowiec et al., 2007; Jonczak et al., 2010). The amount of recycled phosphorus was significantly high, comparative with plantations of poplar Hybrid275 (Dziadowiec et al., 2007).

TABLE 4. Ash and elemental inflow to soil with plant litterfall

Year	Ash	TOC	TN	P	K	Ca
	kg·ha^{-1}					
2007	178.8	1322.0	30.7	4.2	8.3	16.2
2008	167.3	1409.7	23.2	3.6	11.7	15.3
2009	286.6	2611.8	61.0	7.6	26.2	22.4
2010	225.9	1654.7	36.9	5.1	14.2	19.6

CONCLUSIONS

1. The annual influx of litterfall to the soil in a 120-year old beech forest stand between 2007–2010 was within 2.793–5.398 t·ha^{-1}, reaching the highest value in the seed year. The values were typical of Polish forests.
2. The main component of the litterfall were beech leaves, whose contribution was 82.4–84.5% in the non-seed years and 47.2% in the seed year. In the seed year a large contribution was noted for inflorescences, seeds and seed coats – with a total of 39.8%.
3. The mean annual content of nitrogen in the litterfall within 2007–2010 was 0.81–1.13%; phosphorus – 0.126–0.153%; potassium – 0.298–0.485% and calcium – 0.416–0.583%. The highest concentrations of nitrogen, phosphorus and potassium were observed in the beech seeds. In comparison to the remaining fractions, high concentrations of these elements were observed in leaves from spring litterfall. The highest concentration of calcium was noted in leaves from autumn litterfall. In regard to other species of deciduous trees, beech litterfall in the studied forest stand contained low amounts of nitrogen, potassium and calcium, and moderate amounts of phosphorus.
4. In the subsequent years, to the soil were reintroduced with litterfall: 167.3–225.9 kg·ha^{-1} ash particles, 23.2–61.0 kg·ha^{-1} nitrogen, 3.6–7.6 kg·ha^{-1} phosphorus, 8.3–26.2 kg·ha^{-1} potassium and 15.3–22.4 kg·ha^{-1} calcium. The content of reintroduced phosphorus was comparable to other deciduous forests in Poland. The influx of nitrogen, potassium and calcium was low.

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