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DYNAMICS, STRUCTURE AND CHEMISTRY OF LITTERFALL IN HEADWATER RIPARIAN FOREST IN THE AREA OF MIDDLE POMERANIA

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Abstract

The following research on plant litterfall mass, dynamics, structure and chemistry was conducted from 2012 to 2014, on a 40- to 86-year-old stand of black alder (*Alnus glutinosa*) growing in a headwater area of the upper part of the valley of the Kamienna Creek (Middle Pomerania). Litterfall was collected every month with 20 circular traps, dried untill constant weight, divided into fractions, weighed and analyzed. The annual influx of litterfall to the soil during the study period ranged from 3482.5 to 4106.9 kg ha^{-1}, showing a dynamics pattern typical of temperate decidous forests. Leaves constituted the major fraction of litter with share of between 78.0 and 81.6% in its total mass. The contribution (in %) of twigs was 4.9-5.6, flowers 2.8-8.3, fruits 0.2-0.9 and other components 7.6-9.2. The relatively stable environmental conditions of headwater areas and the absence of disrupting factors during the study period were reflected in the low temporal variability of litterfall mass, dynamics and chemical composition of its individual fractions. The average annual pH of litterfall was 4.33-4.57. In general, litter was relatively rich in nitrogen and calcium but poor in phosphorus, potassium and magnesium. The content of Fe, Al and Mn was characteristic for these elements and low when compared to the other macroelements. The low contents of Cu and Zn confirm limited anthropogenic contamination of the investigated ecosystem with these metals. The annual return of the elements to the soil formed a series C>N>Ca>K>Mg>P>Mn>Fe>Al>Zn>Sr>Cu. A relatively large influx to the soil was noticed for nitrogen and calcium. Meanwhile, it was low for potassium, magnesium and phosphorus.

Keywords: litterfall, *Alnus glutinosa*, headwater areas, nutrients, heavy metals.

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INTRODUCTION

Headwater areas constitute transition zones between underground and surficial parts of water cycle in river catchments (Chapman et al. 1993, Jekatierinczuk-Rudczyk 2007, Jonczak 2011*a*). These are open systems in matter and energy transfer, whose functioning is strongly affected by the quantity and quality of supplying waters and their permanent surficial and underground flow. Water, as a causal agent of erosion, plays an important role in the organization of headwaters relief and development of spring niches (Mazurek, Paluszkiewicz 2013). It is also an important factor in the development of associated, usually organic, soils and plant communities (Jonczak 2011*a*). Water flow through headwater areas is accompanied by changes in its chemistry (Jekatierinczuk-Rudczyk 2007). Excess of water, typical of these ecosystems, and usually lush vegetation constituting the source of plant remains, favour formation of small domed bogs and development of Histosols within such formations. Interactions between water, soils and plants in headwater areas are very close and anisotropic (Devito et al. 1996, Karlsson et al. 2005). Production of litterfall, as a substrate for peat mass formation and a source of labile and bioavailable forms of elements, is one of the most important manifestations of these interactions. Quantitative and qualitative characteristics of litterfall affect the properties of individual components of headwater areas, including soils, waters and plants.

Our aim was to characterize the mass, structure, dynamics and chemistry of litterfall in a 40- to 86-year-old stand of black alder (*Alnus glutinosa*) growing on a domed bog in the upper part of the valley of the Kamienna Creek, a left bank tributary of the Słupia River.

MATERIAL AND METHODS

Characteristics of the tree stand

The research covered the years 2012 to 2014, and was conducted in a headwater riparian forest growing in the upper part of the valley of the Kamienna Creek, located in the forest inspectorate Leśny Dwór. The average annual sum of precipitation in this region is about 770 mm and the average annual temperature reaches about 7.6°C. The study plot (40 x 50 m) was located in a 40- to 86-year-old stand of black alder (*Alnus glutinosa*) (54°19'N; 17°10′E) with the tree density of 370 pcs per hectare and tree diameter at breast height from 20 to 66 cm (average 37.3 cm). The investigated tree stand is associated with domed bog composed of highly decomposed alder and alder-sedge peats of the thickness up to 1 m. The peat mass decomposition rate on the von Post scale (Grosse-Brauckmann 1990) ranged from 3 to 9. The underlying soils, classified as Sparic Histosols (WRB 2006), contained up to about 80% of organic matter, whose maximum content was noticed in topsoil. The soils were acidic and slightly acidic, rich in nitrogen and relatively poor in phosphorus. Their functioning under the permanent influence of groundwater flow, especially intensive above the mineral bed, strongly influences the content and vertical distribution patterns of various elements (Jonczak 2011a, Jonczak et al. 2014, 2015a).

Litterfall studies

Litterfall sampling was achieved using 20 circular traps of the diameter 50 cm, distributed over the study plot in a regular grid. Litter was collected every month, dried until constant weight at 65ºC, divided into fractions (leaves, twigs, flowers, fruits, other components), weighed and homogenized for chemical analysis. Leaves were analyzed separately for each month, other components were examined as mixed samples for every season and the remaining fractions (twigs, flowers, fruits) were treated as mixed annual samples. The following analyses were performed on the samples:

– pH with the potentiometric method in a suspension with H_2O in a sample:water proportion of 1:10;
– the content of organic carbon (C) with the Alten method;
– the content of total nitrogen with the Kjeldahl method (distillation unit VELP UDK 127);
– total content of P, K, Ca, Mg, Fe, Al, Mn, Cu, Zn and Sr after digestion of samples in a mixture of 65% HNO_3 and 30% H_2O_2. The content of P in the solution was analyzed by the molybdenum blue method and the remaining elements were assayed by microwave plasma atomic emission spectrometry (Agilent 4100 MP-AES).

Based on the content of individual elements in the litterfall fractions and mass of the fractions, weighted mean annual concentrations of elements were calculated for total litterfall and their return to the soil.

RESULTS AND DISCUSSION

Litterfall mass, dynamics and structure

Mass and dynamics of litterfall in forest ecosystems depend on a number of factors, which can be grouped into three categories, according to the factors characterizing plant communities (species composition, age, health condition and density of trees) (Stachurski, Zimka 1975, Bell 1978, Astel et al. 2009, Jonczak 2011*b*, 2013, Jonczak, Parzych 2014), site conditions (physical and chemical properties of soils, water regime and climate conditions) (Prescott et al. 1999) and factors disrupting its production (extreme weather phenomena, outbreak of pests, impact of man) (Dziadowiec, Plichta 1985, Jonczak, Czarnecki 2008). Annual production of litterfall in the investigated stand between 2012 and 2014 was from 3482.5 to 4106.9 kg ha^{-1} (Table 1),

Table 1

Litterfall mass and structure during 2012-2014

Litterfall components	Mass of litterfall fractions (kg ha^{-1})			Percentage of fractions in total litterfall in the years		
	2012	2013	2014	2012	2013	2014
Leaves – June	44.2	43.3	71.8	1.3	1.8	1.1
Leaves – July	270.0	362.2	343.5	7.8	8.6	8.8
Leaves – August	454.4	422.8	309.0	13.0	7.7	10.3
Leaves – September	717.7	674.4	787.9	20.6	19.7	16.4
Leaves – October	1356.3	1701.9	1739.6	38.9	43.5	41.4
Twigs	172.6	202.2	222.1	5.0	5.6	4.9
Flowers	196.5	339.6	113.8	5.6	2.8	8.3
Fruits	6.1	21.1	36.4	0.2	0.9	0.5
Others – winter	24.6	11.0	12.1	0.7	0.3	0.3
Others – spring	179.9	210.9	176.7	5.2	4.4	5.1
Others – summer	34.2	43.3	117.7	1.0	2.9	1.1
Others – autumn	26.0	74.1	65.5	0.7	1.6	1.8
Annual sum	3482.5	4106.9	3996.2	100.0	100.0	100.0

remaining within the average values for deciduous forests of Poland (Małek 2006, Dziadowiec et al. 2007, Kowalkowski, Jóźwiak 2007, Niewinna 2010, Jonczak 2013). The observed low variability of annual litterfall mass during the study period should be attributed to relatively stable site conditions of headwater areas, particulary in terms of the water regime, as well as the absence of factors disrupting the life functions of trees during the experiment. Litterfall dynamics show trends typical of temperate forests (Figure 1). The majority of its mass was falling in the late summer and early autumn,

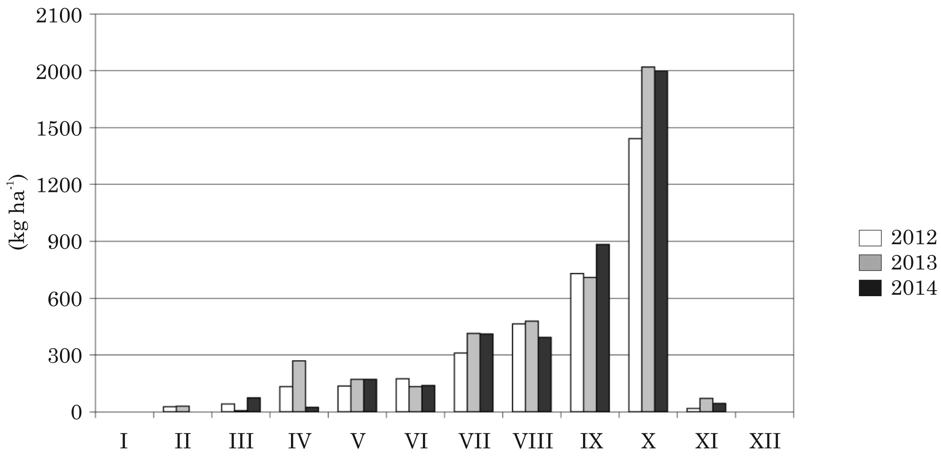

Fig. 1. Litterfall dynamics during 2012-2014

peaking in October. Leaves were the major fraction of litter, constituting 78.0-81.6% of its total mass. The contribution of twigs ranged from 4.9 to 5.6%, flowers from 2.8 to 8.3%, fruits from 0.2 to 0.9% and other components from 7.6 to 9.2% (Table 1).

Litterfall chemistry

Chemical composition of litterfall is a particular characteristic of individual plant species and litter fractions, with the modifying influence of the site-specific conditions and trees' age. Especially large differences in litterfall chemistry are observed between coniferous and deciduous tree species (Augusto et al. 2002, Jonczak 2011*b*).

Every litterfall fraction in the investigated stand had strongly acidic pH, which ranged from 3.31 to 4.92, with average annual values for total litterfall from 4.33 to 4.57 (Table 2). This is a suprisingly low pH, comparable to the values observed by Jonczak (2013) in pine litter (4.25-4.50) and lower than in beech litter (5.30-5.51). The average annual content of ash was within 51.5 and 52.3 g kg^{-1} and in individual fractions from 11.4 to 64.9 g kg^{-1} with the minimum values in fruits (11.4-29.5 g kg^{-1}) and the maximum ones in leaves (48.9-64.9 g kg^{-1}).

Litterfall was relatively rich in nitrogen, whose annual average content was from 18.2 to 20.5 g kg^{-1}. The content of nitrogen among individual fractions showed rather low variability (Table 2). The least nitrogen-abundant were twigs (12.1-14.1 g kg^{-1}) and fruits (11.8-15.4 g kg^{-1}). In contrast, flowers or other components collected during the summer or autumn were the richest in nitrogen. The C:N ratio, which is considered to be a good indicator of litterfall decompsability, ranged from 23.8:1 (leaves collected in June 2012) to 49.2:1 (twigs collected in 2014). Average annual C:N ratios for total litterfall were from 26.8:1 to 32.2:1. These are values typical of tree species associated with fertile forest stands, comparable to the ones noticed by Dziadowiec et al. (2007) in poplar plantations and narrower than observed by Jonczak (2011*b*, 2013) in beech and beech-pine-spruce stands located a few hundred meters from the investigated riparian forest.

In general, the litterfall was poor in phosphorus, although its content was highly variable among the individual fractions, ranging from 0.42 to 1.56 g kg^{-1}. Flowers were the most abundant fraction (1.41-1.56 g kg^{-1}) and leaves collected in July (0.42-0.49 g kg^{-1}) and twigs (0.46-0.59 g kg^{-1}) were the poorest in phosphorus. The average annual content of phosphorus in total litter ranged from 0.57 to 0.65 g kg^{-1} (Table 2). This low content of phosphorus is reflected in wide and very wide ratios of C:P, reaching on average 917.0:1-1079.8:1. The data suggest phosphorus deficiency in the investigated stand. Phosphorus deficit, commonly occuring in forest ecosystems, is another important factor, beside shortage of nitrogen, limiting microbial and plant growth. Translocation of these elements from leaves before autumn is an adaptive mechanism to respond to their defficiency. This phenomenon is

Table 2

pH and the content of ash and macroelements in litterfall

Litterfall components	pH	The content (g kg^{-1}) of					C:N	C:P
		ash	C	N	P	K		
Year 2012								
Leaves – June	4.23	48.9	539.1	22.7	1.28	5.75	23.8	421.4
Leaves – July	4.01	58.7	519.3	18.5	0.49	3.13	28.1	1067.9
Leaves – August	4.20	59.6	516.3	19.5	0.47	3.35	26.5	1107.9
Leaves – September	4.20	57.4	519.6	20.9	0.55	3.56	24.9	946.0
Leaves – October	4.40	53.3	532.5	21.5	0.56	2.91	24.8	957.9
Twigs	4.61	39.1	588.7	14.1	0.59	1.78	41.9	1006.2
Flowers	4.60	32.3	600.1	21.8	1.50	5.34	27.5	398.8
Fruits	3.85	29.5	527.0	15.4	0.76	2.07	34.2	694.0
Others – winter	4.27	41.4	603.8	14.6	0.57	1.29	41.3	1061.2
Others – spring	4.51	37.6	593.6	18.8	1.15	2.78	31.7	517.5
Others – summer	4.58	42.5	602.3	22.7	1.28	2.07	26.6	469.5
Others – autumn	4.65	41.6	596.3	21.3	1.16	2.77	28.0	513.2
Average	4.33	52.3	538.2	20.3	0.64	3.20	26.8	917.0
Year 2013								
Leaves – June	4.13	53.2	505.2	19.7	0.71	3.43	25.6	711.7
Leaves – July	3.99	57.4	542.3	18.0	0.42	3.26	30.1	1288.6
Leaves – August	4.09	56.6	530.9	19.5	0.46	3.10	27.2	1144.4
Leaves – September	4.30	55.6	575.2	20.3	0.52	3.27	28.3	1100.3
Leaves – October	4.61	56.8	540.3	21.9	0.58	3.47	24.7	936.8
Twigs	4.78	37.0	570.6	13.2	0.46	1.68	43.2	1237.0
Flowers	4.91	30.0	589.9	23.4	1.56	6.35	25.3	378.8
Fruits	3.31	13.8	491.4	12.3	0.51	1.91	39.9	961.6
Others – winter	4.46	46.8	566.8	18.2	1.04	1.97	31.1	543.0
Others – spring	4.46	33.6	588.7	18.4	0.85	1.67	32.0	695.8
Others – summer	4.58	48.7	563.9	22.4	1.01	2.20	25.1	557.8
Others – autumn	4.69	45.2	547.2	22.5	1.09	3.99	24.4	502.6
Average	4.47	51.7	553.1	20.5	0.65	3.42	27.4	957.2
Year 2014								
Leaves – June	4.40	51.8	581.9	18.0	0.63	2.36	32.4	930.1
Leaves – July	4.40	58.0	561.6	18.1	0.48	2.87	31.0	1174.7
Leaves – August	4.47	64.9	575.2	18.4	0.50	3.92	31.3	1149.9
Leaves – September	4.53	54.6	561.6	18.3	0.51	3.34	30.7	1099.7
Leaves – October	4.58	54.4	582.9	19.0	0.50	3.30	30.8	1161.2
Twigs	4.89	35.0	594.1	12.1	0.48	1.54	49.2	1229.1
Flowers	4.92	27.1	623.4	21.7	1.41	3.79	28.8	441.5
Fruits	3.45	11.4	538.3	11.8	0.59	2.07	45.5	916.1
Others – winter	4.44	39.3	613.9	16.2	0.66	1.17	38.0	935.2
Others – spring	4.70	29.1	611.7	17.0	0.99	2.54	35.9	620.5
Others – summer	4.88	43.1	570.6	20.4	0.96	1.87	28.0	592.6
Others – autumn	4.52	34.9	582.0	16.6	0.68	1.86	35.0	853.6
Average	4.57	51.5	578.6	18.2	0.57	3.10	32.2	1079.8

observed even in riparian forests, relatively rich in these elements (Dziadowiec et al. 2007). Bioavailability of phosphorus is strongly affected by soil reaction. At pH below 6.5, the element is bound by Fe and Al oxides, whereas in alkaline conditions it forms hardly soluble salts with calcium (Richardson 1985, Sah, Mikkelsen 1986). However, formation of phosphates may be inhibited by organic matter (Kodama, Schnitzer 1980) and anaerobic conditions (Wang et al. 1991). The observed deficiency of phosphorus in the investigated stand resulted from specific conditions of soil development, which occurred under permanent water flow, favouring the leaching of labile fractions of the element.

The content of basic cations (K, Ca, Mg) was highly variable among the individual fractions of litterfall. However, the average year-to-year contents were comparable, ranging from 3.10 to 3.42 g kg^{-1} for K, from 12.70 to 14.63 g kg^{-1} for Ca and from 1.27 to 2.01 g kg^{-1} for Mg (Table 2, 3). The content of calcium in litter fractions ranged from 2.79 g kg^{-1} in fruits collected in 2013 to 16.99 g kg^{-1} in leaves from July 2012. Leaves, which were the richest in this element, contained a quantity between 12.70-16.63 g kg^{-1}. Potassium constituted 3.10-3.42 g kg^{-1} of litter mass, with the lowest content in twigs (1.54-1.78 g kg^{-1}), fruits (1.91-2.07 g kg^{-1}) and other components from winter litterfall (1.17-1.97 g kg^{-1}) and the highest one in flowers (3.79-6.35 g kg^{-1}). Magnesium occurred in the lowest quantities in other components from winter season (0.33-0.81 g kg^{-1}) and in fruits (0.32-0.64 g kg^{-1}), but was the highest in leaves (1.20-2.70 g kg^{-1}).

In general, high contents of Fe and Al observed in soils (a few %) do not correpond to high concentrations of these elements in litterfall, rarely exceeding 0.05% (Jonczak 2011*b*, 2013). In the investigated stand, amounts of Fe in litter ranged from 14.7 to 288.3 mg kg^{-1} (average 106.2-158.4 mg kg^{-1}) and Al from 10.3 to 281.6 mg kg^{-1} (average 36.6-90.0 mg kg^{-1}) – Table 3. The other components and leaves were relatively rich in these elements while flowers, fruits and twigs were the poorest. Manganese occurred in much higher contents: from 303.1 to 364.5 mg kg^{-1} on average, with minimum amounts in fruits and maximum ones in leaves. Much manganese is taken up by microorganisms and plant roots. Its return to the soil with litterfall strongly influences the profile distribution patterns of this element in different soil types (Jonczak 2014).

The uptake by roots and return with litterfall are also important factors influencing the content and profile distribution patterns of copper and zinc (Jonczak 2014). The intensity of the uptake of these important micronutrients is affected by a complex combination of soil physicochemical properties that determine their bioavailability. The content of Cu, Zn and other heavy metals in leaves and needles of some tree species can be used as a measure of anthropogenic environmental contamination with these substances (Čeburnis, Steinnes 2000, Bertolotti, Gialanella 2014, Parzych, Jonczak 2014, Pająk et al. 2015). Their excessive concentrations in litterfall can reduce biological activity and intensity of litter decomposition, even tho-

Table 3

Chemical composition of litterfall

Litterfall components	The content of							
	Ca	Mg	Fe	Al	Mn	Cu	Zn	Sr
	(g kg^{-1})				(mg kg^{-1})			
Year 2012								
Leaves – June	11.50	1.66	118.7	45.3	328.8	8.6	91.8	19.3
Leaves – July	16.99	1.81	178.2	65.2	374.9	5.1	143.6	34.4
Leaves – August	15.51	1.60	166.3	58.3	328.6	4.9	95.1	33.0
Leaves – September	15.41	1.48	165.2	57.9	313.7	5.0	81.7	35.1
Leaves – October	14.38	1.20	134.3	47.4	408.7	4.8	64.4	34.5
Twigs	10.39	0.58	81.0	32.4	185.5	5.5	54.4	36.2
Flowers	5.10	0.79	32.9	18.8	142.7	5.9	67.2	12.0
Fruits	4.02	0.50	50.4	38.6	87.5	6.2	74.1	10.2
Others – winter	8.62	0.33	169.6	129.4	122.4	6.5	161.1	26.6
Others – spring	7.10	0.86	144.9	87.6	220.4	7.2	185.6	17.1
Others – summer	8.02	0.87	243.1	127.6	194.2	7.8	393.5	17.4
Others – autumn	9.54	0.82	141.9	88.5	234.4	6.4	119.2	20.8
Average	13.65	1.28	141.5	53.7	333.2	5.2	88.7	31.8
Year 2013								
Leaves – June	12.85	1.68	141.1	55.0	370.9	4.3	135.5	24.9
Leaves – July	14.34	1.83	130.5	43.0	344.7	3.0	43.7	28.5
Leaves – August	14.64	1.57	173.1	55.0	317.5	4.6	82.7	30.7
Leaves – September	14.02	1.33	118.5	36.9	266.0	3.1	60.5	31.4
Leaves – October	14.22	1.34	101.2	26.9	375.8	4.9	26.6	32.7
Twigs	10.29	0.52	69.3	26.5	195.4	4.6	39.6	33.7
Flowers	4.91	0.84	14.7	10.3	131.7	4.9	32.8	10.6
Fruits	2.79	0.32	34.3	29.1	69.1	2.2	76.7	9.1
Others – winter	7.12	0.52	149.3	122.7	207.9	3.6	315.6	17.6
Others – spring	6.90	0.56	99.8	89.7	138.1	4.8	258.8	16.8
Others – summer	8.83	0.86	175.8	112.4	174.8	4.3	161.6	20.0
Others – autumn	11.42	1.16	97.3	54.5	350.3	3.0	54.7	24.6
Average	12.70	1.27	106.2	36.6	303.1	4.3	56.6	28.8
Year 2014								
Leaves – June	14.72	2.44	188.4	96.7	495.2	3.9	120.0	38.3
Leaves – July	16.70	2.70	197.0	94.3	455.8	3.4	79.9	44.4
Leaves – August	16.05	2.66	171.0	74.1	387.9	3.1	58.8	45.7
Leaves – September	16.29	2.19	168.2	84.7	340.1	3.0	58.3	48.1
Leaves – October	15.51	2.06	156.8	91.4	425.1	3.1	36.4	44.8
Twigs	11.02	0.92	108.1	63.8	201.5	4.1	43.9	43.6
Flowers	6.52	1.23	61.7	43.2	139.0	4.2	116.7	19.8
Fruits	3.70	0.64	81.1	68.6	56.0	3.2	50.1	14.6
Others – winter	8.95	0.81	288.3	281.6	105.3	5.4	233.2	27.5
Others – spring	7.68	1.16	125.1	107.4	207.7	5.3	218.0	23.0
Others – summer	11.18	1.40	208.5	159.8	221.3	5.7	230.9	33.5
Others – autumn	12.07	1.04	147.4	135.6	161.6	4.6	59.9	38.6
Average	14.63	2.01	158.4	90.0	364.5	3.4	65.2	42.9

ugh the limit values are relatively high (Tyler 1992). In forest ecosystems, litterfall and ectohumus are usually more abundant in Cu and Zn than is the soil solum (Jonczak 2014, Jonczak, Parzych 2014). In the investigated stand, the average annual contents of Cu in litter ranged from 3.4 to 5.2 mg kg^{-1} and Zn from 56.6 to 88.7 mg kg^{-1} and in soils 6.1-13.1 mg kg^{-1} and 2.4-66.8 mg kg^{-1} respectively (Jonczak et al. 2014). The content of Cu in individual litter fractions varied slightly while that of Zn was highly variable. The highest concentrations of Zn were usually noticed in other components and the lowest ones were in twigs, flowers and leaves from the autumn maximum.

The element strontium is rarely studied in plant litters. Its average annual content in the investigated stand ranged from 28.8 to 42.9 mg kg^{-1}. The lowest concentrations were noticed in flowers and fruits, while the highest ones were in leaves, especially these colected during August and October (Table 3).

Elements return to the soil with litterfall

Elements returned to soil through litterfall constitute one of the most important links in matter and energy balance in forest ecosystems, in addition to acting as a mechanism through which plant communities influence soil cover (Augusto et al. 2002, Jonczak 2012). In nutrient-poor forest stands, the annual return of elements to soil is a critical factor in their turnover that determines stability of ecosystems. Most of nutrient pools gradually released during litterfall decomposition are reincluded in biological turnover. Some amounts can be leached beyond the reach of root systems or released into the atmosphere. The annual influx of elements to soil with litterfall is a resultant of litter mass and its chemical composition. Organic carbon, which constitutes about 50% of dry weight of organic litter, always comes in largest amounts. In the investigated stand, the annual influx of this element ranged from 1874.35 to 2312.26 kg ha^{-1} (Table 4). We noticed a relatively large influx of nitrogen (70.83-84.20 kg ha^{-1}) and calcium (47.54-58.47 kg ha^{-1}), but a low one of potassium (11.16-14.05 kg ha^{-1}), magnesium (4.46-8.05 kg ha^{-1}) and phosphorus (2.24-2.66 kg ha^{-1}). The influx of the remaining elements was much lower, amounting to 1.16-1.46 kg ha^{-1} for manganese, 0.44-0.63 kg ha^{-1} for iron, 0.15-0.36 kg ha^{-1} for aluminium, 0.23-0.31 kg ha^{-1} for zinc, 0.11-0.17 kg ha^{-1} for strontium and only 0.01-0.02 kg ha^{-1} for copper. Leaves, the major component of litterfall, played a predominant role in the return of the elements to soil. Results of Jonczak et al. (2015*b*) showed high intensity of leaf litter decomposition and nutrient release in a tree stand.

Table 4

Return of ash and elements to soil with litterfall during 2012-2014

Litterfall components	Return of components to soil (kg ha^{-1}) in the years			
	2012	2013	2014	average 2012-2014
Ash	182.21	212.27	205.66	200.05
C	1874.35	2271.60	2312.26	2152.73
N	70.83	84.20	72.87	75.97
Ca	47.54	52.16	58.47	52.72
K	11.16	14.05	12.39	12.53
Mg	4.46	5.22	8.05	5.91
P	2.24	2.66	2.27	2.39
Mn	1.16	1.24	1.46	1.29
Fe	0.49	0.44	0.63	0.52
Al	0.19	0.15	0.36	0.23
Zn	0.31	0.23	0.26	0.27
Sr	0.11	0.12	0.17	0.13
Cu	0.02	0.02	0.01	0.02

CONCLUSIONS

1. Annual production of litterfall in the investigated headwater riparian forest between 2012 and 2014 corresponded to average quantities recorded for Polish deciduous forests, ranging from 3482.5 to 4106.9 kg ha^{-1}. Its dynamics showed trends typical of temperate forests and was not disrupted by internal or external factors. Therefore, the year-to-year variability in litterfall mass, structure and chemistry of the individual fractions was relatively low.

2. Leaves were the major component of litterfall, constituting 78.0-81.6% of its total mass. The contribution of twigs was 4.9-5.6%, flowers 2.8-8.3%, fruits 0.2-0.9% and other components 7.6-9.2%.

3. Litterfall was strongly acidic, however pH varied among particular fractions, ranging from 3.31 to 4.92.

4. In general, litterfall was relatively abundant in nitrogen and calcium but poor in phosphorus, potassium and magnesium. The lowest contents of the elements were usually noticed in fruits, twigs and sometimes in other components while the highest ones were in leaves and flowers.

5. The contents of iron, aluminium and manganese were among average values for deciduous litters. The low contents of Cu and Zn were typical of uncontaminated areas.

6. In terms of the annual return to the soil with aboveground litterfall, the elements formed a series: C>N>Ca>K>Mg>P>Mn>Fe>Al>Zn>Sr>Cu. A relatively large influx to the soil was noticed for nitrogen and calcium, while being low for potassium, magnesium and phosphorus. The influx of the remaining elements did not exceed 1 kg ha^{-1}.

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