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PRECIPITATION AND DUFF FALL AS NATURAL SOURCES OF NITROGEN AND PHOSPHORUS FOR FOREST SOILS IN THE SŁOWIŃSKI NATIONAL PARK

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Abstract

Every year forest soils are enriched with nitrogen and phosphorus compounds due to the fall of leaves and litter of conifer needles, mineralization of ground cover and decaying tree roots, as well as precipitation. The process has been examined in two forest ecosystems: a mixed forest (plot I) and a young wood (plot II). The overall fall of duff collected in the young wood of the Słowiński National Park (plot II) has been 3.014 t/ha · year, which constitutes 69.35% of the fall collected in the mixed forest (plot I) on this territory (4.346 t/ha · year). The maximum intensity of duff fall occurred in autumn months and constituted 62.36% and 64.20% of annual fall respectively. Totally, 46.96 kg/ha · year of N and P were supplied to the soil of the plot I and 22.04 kg/ha · year in the case of the plot II. The precipitation enriched the soils of the mixed forest by 33.66 kg/ha · year of nitrogen and 1.19 kg/ha · year of phosphorus, the soils of the young wood – by 23.06 kg/ha · year of nitrogen and 0.92 kg/ha · year of phosphorus.

Key words: nitrogen, phosphorus, duff fall, precipitation, mixed forest, young wood

INTRODUCTION

Annual duff plays an important role in functioning of forest ecosystems (Prusinkiewicz et al. 1974) as well as precipitation which constitutes a certain kind of natural source of biogenic elements for forest soils. Nitrogen and phosphorus are vital soil components necessary for plant growth and development. Every year forest soils are enriched with those elements due to the fall of leaves, litter of conifer needles, mineralization of ground cover and decaying of tree roots as well as precipitation. Trophic substances, which are a valuable source of nitrogen and phosphorus compounds, are returned to the soil with the fall of litter of conifer needles, leaves, cone seeds, outer bark and branches. Banaszuk (1996) was widely engaged in the quantitative research of duff in the north-eastern regions of Poland. The subject matter of Prusinkiewicz and others' research (1974) was the amount of biogenic elements returned to the soil together with annual duff fall. Also Stachurski and Zimka (1975, 1976) and Zimka himself (1989) dealt with the same problem and they ascertained that the largest amounts of nitrogen and phosphorus were withdrawn during an autumn period of leaves ageing. Wachowska-Serwatka (1966), on the other hand, made an attempt to examine the dependence of soil, vegetation and forest duff. From the researches of various authors (among others Ovington 1954, Wachowska-Serwatka 1966) it comes out that seasonal changes of nitrogen and mineral constituents content in the duff, soil and plants are closely connected with temperature and the amount of precipitation, and also, with air and soil humidity. An average high temperature and high humidity positively influence the processes of mineralization. In the course of decay and mineralization the mass of duff and the content of mineral constituents in it gradually decrease. The elements getting into the soil are gradually taken by plants, especially intensively in the period of their maximum growth. The process of releasing nutritive substances stored in the duff is the most crucial process on which functioning of the whole ecosystem depends.

Duff fall plays a particularly important role in the forests covering poor podsols. Humification processes of plant fall were presented by Dziadowiec and Kwiatkowska (1980). As a result of their mineralization, simple chemical compounds are supplied to the soil. The rate of duff mineralization depends on many factors and is one of the measures of the matter cycle efficiency in the ecosystem (Banaszuk 1996). Studying the rate of the nitrogen release process from organic remnants of plant fall, Gołąb estimated the time needed for decreasement of 50% of the initial dry mass of beech and hornbeam leaves. He also drew important conclusions concerning the processes of nitrogen release from the plant material. According to his researches, the process of nitrogen release begins at the moment of reaching by the material under analysis a relatively narrow ratio of carbon to nitrogen, which for forest communities ranges from 20:1 to 30:1.

On the other hand, Kasza (1977) and Tyszka et al. (1998) examined a changeable chemical composition of precipitation waters. The chemical mechanism of precipitation waters was also a subject matter of studies by Ostrowska et al. (1994). Precipitation water collected in the open space and under the heads of forest trees was analyzed by Stachurski and Zimka (1984), Stachurski (1987). They described the processes occurring in the course of rain waters flow through the zone of tree heads in forest ecosystems from the point of view of quantity. Among the results of their works they stated that almost 80% of the nitrogen coming from the atmosphere is absorbed in the heads of trees and so rain waters reaching the bottom of the forest are poorer in nitrogen content by this value. Similar values are obtained in forests of different species structure of the stand of trees. It is a fully dynamic process controlled by biotic factors and its final result depends on the scope of activity of phytophages that enrich rain waters with nitrogen (Stachurski and Zimka 1984).

The purpose of the present paper was to find out what amounts of nitrogen and phosphorus are annually turned back with the duff fall and what amounts of them are brought in the form of precipitation to the soils of two different ecosystems on the territory of the Słowiński National Park.

STUDY AREA

The research was carried out on the territory of the Słowiński National Park (SNP), (Fig. 1). For the purpose of the study two plots, of the area of 0.5 ha each were chosen. Plots are located on the territory of the Protection Zone of Smołdziński

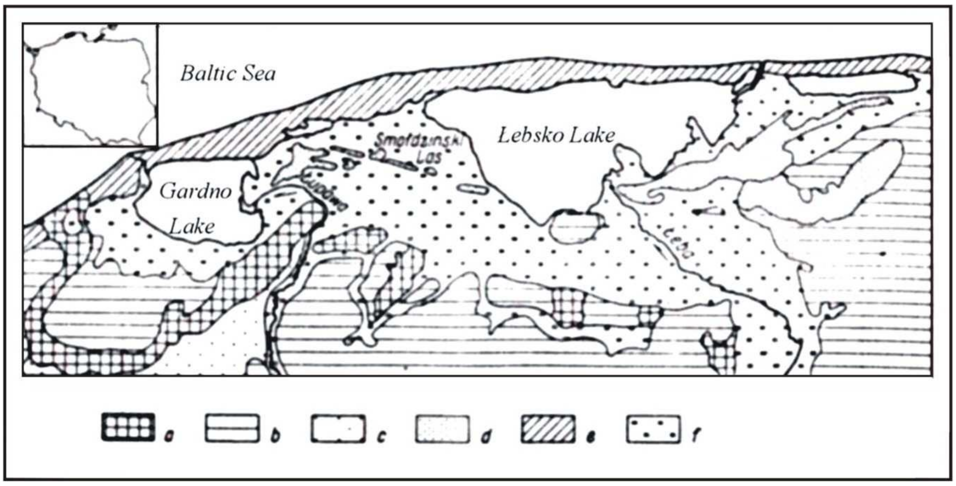

Fig. 1. Geo-morphologic sketch of Gardno – Łebsko Lowland: a) head moraine, b) ground moraine, c) outwashes, d) late-glacial Aeolian forms, e) holocene Aeolian form, f) forms of organogenic and mineral accumulation in valley bottoms, proglacial stream valleys and in depressions

Forest and situated on two different sides of the road running from Smołdziński Forest to Czołpino, in the distance of 600 m from each other (Fig. 2). One of them was based on the territory of a mixed forest with quite high, changeable level of underground waters, in the distance of about 1500 m from the sea; the other one – on the territory of a young wood, about 900 m away from the sea, with a similarly located level of underground waters. The changes of underground water levels are connected with precipitation as well as with seasonal changes of lake water levels (Lake Dołgie Wielkie, Lake Łebsko). Lakes soften the amplitudes and slow down the clogging of waters and lowering of water levels (Tobolski et al. 1997). The Protection Zone of Smołdziński Forest is situated on Gardnieńsko-Łebska Lowland being an integral part of the forest area of the Słowiński National Park.

The species dominating on plot I are the pine-tree and the birch-tree of a total number of 520 trees, and the average distance between them is 3.10 m. The soils of plot I have been classified as gley mezotrophic podsols. The plot II is covered by a pine stand (715 trees) and the average distance between trees is 2.64 m. Those distances have been quoted according to Alexandrowicz 1972. The soils of the plot II are typical poor podsols. The coastal location and the sea climate cause that seaside woods significantly differ from inland woods in the kind of soils and floristic composition.

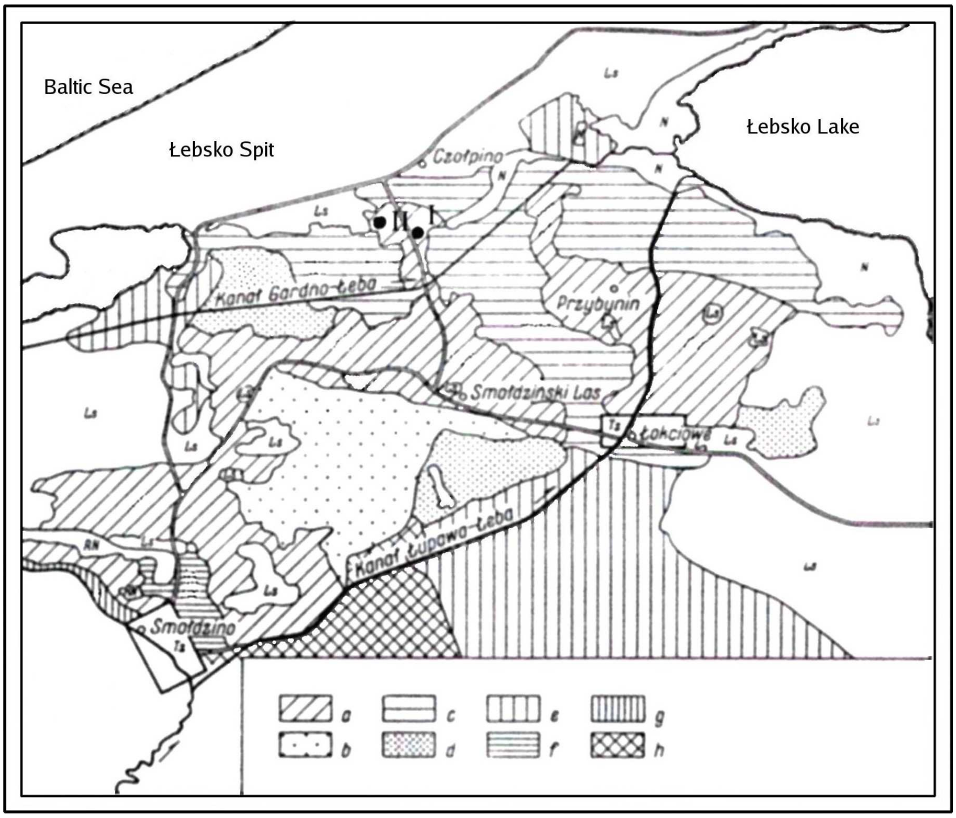

Fig. 2. Distribution of soils concerned:
a) gley-podsol-decay soils, b) mineral-decay soils c) shallow peat-decay soils d) medium-depth peat-decay soils e) deep peat soils f) rigosol gley-podsols, g) proper fen soils h) complex of peat and mineral soils, Ls- forest, N- barren land, RN – waste land (farming), Tz – village premises, I – area I, II – area II

In shaping habitats and communities an important role is played by strong winds, a relatively low average annual temperature, a relatively short and mild winter, a long period without ground frost, a short and mostly warm summer, a long autumn, quite low annual precipitation (about 700 mm) and also, high air humidity (Matuszkiewicz 2002).

MATERIAL AND METHODS

On the two research plots there plant fall catchers of the total surface of 3.27 m^2 were installed. According to Satoo and Madgwick (1982, after Sienkiewicz and Małachowska 1989) it is a sufficient surface to assess duff fall. In places chosen at random in the open space and under tree heads, 1 m above the ground there were placed polyethylene containers for precipitation equipped with double protective filters

(Stachurski and Zimka 1984). The measurements of plant fall and precipitation were carried out seven times during the year 2003. On average, every six weeks the content of the catchers and containers was taken out, sent to the laboratory, dried to a constant mass and divided into adequate fractions: needles, leaves, outer bark, small branches, seeds and others. Adequate chemical analyses were conducted. The content of total nitrogen and total phosphorus was determined by prior mineralization of samples in the mixture of sulfuric acid and 30% of hydrogen peroxide. After mineralization total nitrogen was determined by using the Kiejdahal's method and phosphorus – by a molybdate method. Mineral nitrogen and phosphorus available for plants were determined with Crowther-Bilarge's method (Nowosielski 1974) through extraction of 5% solution by using of K_2SO_4. In obtained filtrate nitrate nitrogen ($N\text{-}NO_3$) was determined by using of sodium salicylate; ammonia nitrogen ($N\text{-}NH_4$) – by Nessler's method and phosphate phosphorus ($P\text{-}PO_4$) – by a molybdate method.

RESULTS

Duff falls during the whole year with various intensity. The results of quantitative measurements of duff fall performed in 2003 on the territory of the mixed forest and the young wood have been presented in table 1. The total duff fall collected in the young wood was 3.016 t/ha · year, which constituted 69.36% of the fall collected in the mixed forest (4.350 t/ha · year). On the plot I in the organic fall there dominated fractions of needles 32.99% and leaves 27.93%. The least amount was constituted by bark – 4.81% (211 kg/ha·year). The content of plant fall on the plot II appears

Table 1

Share of particular fraction masses in the duff fall on the territory of the mixed forest and the young wood

Fall fraction	Duff fall			
	Mixed forest		Young wood	
	[t/ha · year]	[%]	[t/ha · year]	[%]
Leaves	1.214	27.93	-	-
Small branches	0.841	19.34	0.200	6.78
Needles	1.434	32.99	1.661	55.13
Bark	0.211	4.81	0.910	29.97
Seeds	0.650	14.93	0.245	8.12
Total	4.350	100.00	3.016	100.00

Table 2

Share of particular fractions of autumn fall in a yearly fall

Fall fraction	Autumn fall [t/ha · year]		Share in a yearly fall [%]	
	Mixed forest	Young wood	Mixed forest	Young wood
Leaves	1.140	0.000	26.25	-
Small branches	0.349	0.030	8.03	3.98
Needles	1.095	1.420	25.19	47.11
Bark	0.074	0.420	1.68	12.25
Seeds	0.052	0.065	1.21	0.86
Total	2.710	1.935	62.36	64.20

Table 3

Dynamics of overall duff fall in the mixed forest and the young wood

Fall fraction	Duff fall			
	Mixed forest		Young wood	
	[kg/ha · year]	[%]	[kg/ha · year]	[%]
Spring	481.97	11.09	109.38	3.63
Summer	1016.09	23.38	527.40	17.50
Autumn	2710.17	62.36	1934.79	64.20
Winter	137.77	3.17	442.12	14.67
Total	4346.00	100.00	3013.69	100.00

slightly different. Here the dominating fraction were also needles (55.13%), but second was bark (29.97%), and the least in quantity were small branches – 6.78% (200 kg/ha · year).

The maximum intensity of plant fall was recorded on both examined plots in autumn months (Tables 2 and 3). Then there was collected from 62.20% (plot I) up to 64.36% (plot II) of the annual duff fall. The dominating fractions were leaves whose fall in autumn constituted 26.25% of yearly fall (plot I) and needles (25.19% – plot I and 47.11% – plot II). On both examined areas big amounts of needles were collected, on the plot I – 1.095 t/ha·year and 1.420 t/ha · year on the plot II. In comparable amounts there were collected seeds: 0.052 t/ha · year and 0.065 t/ha · year respectively.

The dynamics of duff fall in the mixed forest and the young wood are partly similar, namely on both plots the maximum organic fall occurs in the autumn period, a little less duff falls in summer, that is 23.38% in the mixed forest and 17.50% in the young wood (Tab. 3). The minimum fall was recorded in winter on the plot I (3.17%) and in spring on the plot II (3.63%). Those differences result from various kinds of trees covering the plots under examination. It is connected, first of all, with the fall of needles prolonging for winter months in the young wood.

The chemical analysis of plant fall showed the presence of nitrogen and phosphorus compounds. The total content of nitrogen contained in falling duff in the mixed forest was 45.92 kg/ha · year – (1.06%) and was twice as big as in the young wood – 21.14 kg/ha·year (0.70%) (Tab. 4). The dominating form of nitrogen in the fall of duff was organic nitrogen and constituted 97.0% of T-N (plot I) and 99.0% of T-N (plot II). Inorganic forms ($N\text{-}NH_4$ and $N\text{-}NO_3$) constituted, on the other hand, 1-3% of overall nitrogen (T-N). The analyzed duff contained much smaller amounts of phosphorus compounds, that is about 1.04 kg/ha·year, which constituted 0.024% of the overall mass of collected duff (plot I) and 0.90 kg/ha · year, which constituted 0.030% (plot II). Organic phosphorus constituted from 92.3% (plot I) up to 94.4% (plot II) of overall phosphorus (T-P). Phosphate phosphorus in the duff of both examined plots constituted 0.002% of the whole. Totally, in the form of organic fall there were supplied about 46.96 kg/ha · year of N and P to the soil of the plot I and 22.04 kg/ha · year in the case of the plot II.

Table 4

Chemical composition of plant fall in the mixed forest and the young wood

Chemical composition	Mixed forest		Young wood	
	[kg/ha · year]	[%]	[kg/ha · year]	[%]
T-N	45.92	1.060	21.14	0.700
$N\text{-}NO_3$	0.15	0.004	0.16	0.005
$N\text{-}NH_4$	1.21	0.029	0.06	0.002
N-org.	44.56	1.027	20.93	0.694
T-P	1.04	0.024	0.90	0.030
$P\text{-}PO_4$	0.08	0.002	0.05	0.002
P-org.	0.96	0.022	0.85	0.028

The most of nitrogen (T-N) was contained in the fraction of needles – 15.15 kg/ha · year (plot I) and 11.65 kg/ha · year (plot II). In that, nitrogen ($N\text{-}NO_3$) constituted 0.05 kg/ha · year – (0.33%, plot I) and 0.09 kg/ha · year – (0.77%, plot II), ammonia nitrogen ($N\text{-}NH_4$) 0.4 kg/ha · year – (2.64%, plot I) and 0.033 kg/ha ·year – (0.28%, plot II). Organic nitrogen constituted about 97% of T-N (plot I) and 99% of T-N (plot II).

The maximum amount of phosphorus (T-P) was supplied to the forest soils of the plot I by seeds, needles and leaves (respectively: 1.16, 0.34 and 0.29 kg/ha · year). The soils of the plot II were enriched with overall phosphorus mainly thanks to the

Table 5

Content of different forms of nitrogen and phosphorus in duff fractions in the mixed forest and the young wood

Fall fraction	Duff fall													
	Mixed forest							Young wood						
	T-N	$N-NO_3$	$N-NH_4$	Norg.	T-P	$P-PO_4$	Porg.	T-N	$N-NO_3$	$N-NH_4$	Norg.	T-P	$P-PO_4$	Porg.
	[kg/ha·year]													
Leaves	12.83	0.04	0.340	12.45	0.29	0.020	0.27	-	-	-	-	-	-	-
Small branches	8.75	0.03	0.230	8.62	0.20	0.020	0.18	1.43	0.01	0.004	1.42	0.06	0.003	0.06
Needles	15.15	0.05	0.400	14.70	0.34	0.020	0.32	11.65	0.09	0.033	11.54	0.50	0.028	0.47
Bark	2.21	0.01	0.060	2.14	0.05	0.000	0.05	6.33	0.05	0.018	6.27	0.27	0.015	0.25
Seeds	6.86	0.02	0.000	6.65	1.16	0.010	0.14	1.72	0.01	0.005	1.70	0.07	0.004	0.07
Total	45.92	0.15	1.210	44.56	1.04	0.080	0.96	21.14	0.16	0.060	20.93	0.90	0.050	0.85

T-N – overall nitrogen, T-P – overall phosphorus, 2.21 – minimum values for a particular plot needles 0.5 kg/ha·year and bark 0.27 kg/ha·year. In that amount, inorganic phosphorus constituted 0.026 kg/ha · year (7.6%, plot I) and 0.028 kg/ha·year (5.6%, plot II). The dominating form of phosphorus in falling duff was organic phosphorus. The poorest fractions in respect of biogenic elements there appeared on the plot I – the fraction of bark and on the plot II – the fraction of branches. Also, leaves were characterized by a big amount of nitrogen (12.83 kg/ha · year).

Needles and leaves also contained the biggest amount of phosphorus. The content of organic phosphorus in the needles from the plot I amounted to 0.32 kg/ha · year and from the plot II to 0.47 kg/ha · year (Tab. 5), and inorganic phosphorus respectively 0.020 and 0.028 kg/ha · year. It should be stated that the content of phosphorus in the needles from the young wood is by 47% bigger than in the needles from the mixed forest. On the other hand, the content of nitrogen in the needles from the mixed forest is by 30% bigger than in the young wood.

It results from table 6 that the most intensive precipitation took place in July and August (87.8 and 84.3 mm) and in October (100,6 mm). High temperatures in that period of intensive vegetation (18.2 and 17.0°C) and relatively high air humidity for

Table 6

Chosen atmospheric parameters

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Sum of precipitation [mm], **Kluki**	57.4	6.9	12.5	24.3	35.2	45.3	87.8	84.3	59.6	100.6	20.4	65.4	49.9
Average relative air humidity [%], **Gać**	84.3	81.5	78.7	76.1	77.1	76.1	86.3	84.6	85.8	87.8	94.2	89.4	83.5
Temperature [°C], **Gać**	-1.2	-3.6	1.2	5.1	12.7	15.8	18.2	17.0	13.2	5.8	5.4	2.9	7.7

Kluki, Gać – localities situated near Smołdziński Forest (area of SNP)
Data of the Climatology and Hydrology Department – Institute of Geography of the Pomeranian Pedagogical University of Słupsk

Table 7

Chemical composition of precipitation

Spot of collecting fall	T-N	$N\text{-}NH_4$	$N\text{-}NO_3$	T-P
	[kg/ha · year]			
Open space	20.88	8.47	12.34	0.42
Under trees, I	35.45	13.07	20.59	1.19
Under trees, II	26.58	8.49	14.57	0.92

I- mixed forest, II- young wood, T-N – overall nitrogen, T-P – overall phosphorus
Chemical composition calculated on the basis of yearly amount of precipitation in 2003 (Kluki) – 599.6 mm (data of the Climatology and Hydrology Department – Institute of Geography of the Pomeranian Pedagogical University of Słupsk)

the whole year (76.1%-94.2%) were favourable to the process of mineralization of duff. The yearly amount of precipitation in 2003 was 599.6 [mm]. This value was used for quantitative content calculation of nitrogen and phosphorus compounds supplied to forest soils together with rain water. The results of the chemical composition of precipitation have been shown in table 7.

In 2003 precipitation supplied 20.88 kg/ha · year of nitrogen (T-N) and 0.42 kg/ha · year of phosphorus (T-P) to the area of the analyzed plots in Smołdziński Forest. However, much bigger amounts of these biogenic substances reached the forest soils due to the elution of particular ions (NO_3^-, NH_4^+, PO_4^{3-}) from leaves by raindrops. The soils of the plot I were enriched with 33.66 kg/ha · year of nitrogen (T-N) and 1.19 kg/ha · year of phosphorus (T-P), and the soils of the plot II – with 23.06 kg/ha · year of (T-N) and 0.92 kg/ha · year of (T-P). The dominating form of nitrogen was the nitrate form (NO_3^-) and constituted 61.17% of (T-N) on the plot I and 63.18% of (T-N) on the plot II. Ammonium ions (NH_4^+) constituted a smaller content, only 38.83% of (T-N) on the plot I and 36.82% of (T-N) on the plot II. The inflow of phosphorus was also different. Almost three times more of phosphorus compounds – 1.19 kg/ha · year reached the soils of the mixed forest compared to those in the open space, and in the case of soils of the young wood – twice as much, namely 0.92 kg/ha · year.

DISCUSSION

The amounts of collected plant fall on both examined plots (3.016 t/ha · year – young wood and 4.346 t/ha · year – mixed forest) do not differ much from those quoted in the scientific literature. The average amounts of organic fall collected in a pine wood of central Poland are: 4.65 t/ha in Piski Primeval Forest (Puszkar et al. 1972), 4.66 t/ha in Kampinoski Primeval Forest (Wójcik 1970), 3.7-3.8 t/ha in Piwnicki Forest (Prusinkiewicz et al. 1974) and 2.8-3.6 t/ha in the Sanctuary Szelągówka--Biebrzańska Valley, (Banaszuk 1996). The results of the amounts of organic fall obtained from those territories of Poland reach on average about 4 t/ha. The amount of collected organic fall depends, among others, on the density of trees covering particular plots under analysis. The bigger the density of trees, the bigger amounts of collected duff. The maximum intensity of duff fall occurs in autumn months and constitutes 62.36% and 64.20% of the annual fall. Similar results (about 40-60%) were obtained by Prusinkiewicz et al. (1974), and also Banaszuk, (1996). The dominating fractions in the autumn fall are mainly leaves (26.25% – plot I) and needles (25.19% – plot II).

The chemical composition of duff fall depends on numerous factors, among others, the trophic state of a particular ecosystem, humidity of soils and air as well as the average daily temperatures in a particular vegetation period. The more favourable conditions of development, the richer in nitrogen and phosphorus compounds the duff fall. The content of nitrogen in the mixed forest amounted to 45.92 kg/ha · year (1.06%) and 21.14 kg/ha · year (0.70%) in the young wood and the content of phosphorus – 1.04 kg/ha · year (0.024%) in the mixed forest and 0.9 kg/ha · year (0.03%)

in the young wood. The results of chemical composition of the collected duff do not differ from the results quoted in the scientific literature. Similar results were obtained by Wachowska-Serwatka in the duff of beech leaves (0.81-1.95% of nitrogen and 0.08-0.149% of phosphorus). The content of nitrogen in plant fall quoted by Prusinkiewicz et al. (1974) amounts on average to 45 kg/ha (1.1%) and the content of phosphorus about 4 kg/ha (0.09%). In the collected duff there was found a much smaller amount of phosphorus compounds. Almost 3-times lower content of that biogene may be caused by a low content of phosphorus in the soil which is a poor podsol located on the dunes.

Biogenic elements contained in plant fall will successively enrich root systems due to slow mineralization, allowing the development and growth of vegetation in subsequent vegetation seasons. Slow release of biogenic elements from the duff gives a chance of their economic use by plants during the whole year.

Too general literature data made it impossible to compare the contents of nitrogen and phosphorus compounds in particular fractions of the duff fall.

The inflow of NH_4^+ and NO_3^- ions together with rainwater was clearly different on both research surfaces. In the deciduous stand nitrate and ammonia ions determined the amount of nitrogen brought to soils, and in the young wood only nitrate ions. The content of nitrogen and phosphorus in the fall under tree heads is much bigger. On the plot I the amount of nitrogen increased by 1.62 times (61.75%) and on the plot II by 1.11 times (10.81%). In the case of phosphorus that increase was 2.83 times higher (283.30%) on the plot I, and on the plot II – 2.19 times (219.05%). The amounts of particular ions in the fall under tree heads are frequently multiplied in relation to those in the fall in the open space. It is mainly associated with removing from the surface of leaves the substances coming from the atmosphere and washing out the components from the leaves. In overall balance the process of elution dominates over their accumulation in respect of quantity. Similar relations in research results were obtained by Tyszka et al. (1997). The surface of leaves, which is significantly bigger than the surface of needles in the young wood, may have some influence on the results. As a consequence, the bigger surface of contact with rainwater may partly influence the effect of elution.

CONCLUSIONS

– The amount of the duff fall depends on the density of afforestation on the plot under examination and on the state of trophicity of a particular ecosystem.
– The richer the ground in nitrogen and phosphorus compounds, the bigger amounts of those compounds are taken by flora and the richer in those compounds is the falling duff.
– In the mixed forest an annual duff fall is much bigger than in the young wood.
– The biggest share in the duff fall of the examined forest ecosystems had needles and leaves.
– The maximum plant fall occurs in autumn months independently of the kind of forest.

- Every year duff supplies the forest soils of Smołdziński Forest with 21 up to 46 kg/ha of nitrogen compounds and about 1 kg/ha of phosphorus compounds.
- Plant fall in the mixed forest is characterized by a higher content of nitrogen and a lower content of phosphorus than in the young wood.
- Among particular fractions of plant fall needles and leaves contain the most of nitrogen and phosphorus.
- Precipitation also brings to soils significant amounts of nitrogen and phosphorus. In 2003 23.06-33.66 kg/ha · year of nitrogen and 0.92-1.19 kg/ha · year of phosphorus compounds reached the forest soils of Smołdziński Forest. A crucial role in that inflow is played by substances washed out from trees by rain.

REFERENCES

Alexandrowicz B. W., 1972. Typologiczna analiza lasu. (Typological analysis of forest). PWN, Warszawa, (in Polish).

Banaszuk P., 1996. Dynamika opadu ścioły w zbiorowisku boru wilgotnego *Vaccinio Myrtilli-Pinetum* i boru świeżego *Peucedano- Pinetum* w rezerwacie Szelągówka. (Dynamic of the plant fall in the gathering of humid forest *Vaccinio Myrtilli-Pnetum* and recent forest *Peucedano- Pinetum* in Szelągówka reserve). *Zesz. Nauk. Polit. Białost. Inż. Środ.* 109, 9, 82-99, (in Polish).

Dziadowiec H., Kwiatkowska M., 1980. Mineralization and humification of plant fall In mixed forest stand of the reserve „Las Piwnicki" near Toruń, *Ecol. Pol.* 28, 1, 111-128.

Gołąb Z., 1978. Zmiany chemiczne zachodzące w liściach bukowych i grabowych podczas ich rozkładu w naturalnych warunkach. (Occuring chemical changes in beech and hornbeam leafs during their disintegration in natural conditions). *Rocz. Gleb.* XXIX, 2, 67-81, (in Polish).

Kasza H., 1977. Inflow of nitrogen and phosphorus to the dam reservoir at Goczałkowice in the years 1973-1975. *Acta Hydrobiol.*, 19, 1, 23-42.

Matuszkiewicz J. M., 2002. Zespoły leśne Polski. (Forest-groups of Poland). PWN, Warszawa, (in Polish).

Nowosielski O., 1974. Metody oznaczania potrzeb nawożenia. (Methods of determination the needs of manureing). PWRiL, Warszawa, (in Polish).

Ostrowska K., Błaszczyk L., Dziadowicz H., 1994. Nitrogen and phosphorus in precipitation water of forest ecosystems. *Pol. Ecol. Stud.*, 20, 2, 122-128.

Ovington J. D., 1954. Studies of the development of woodland conditions under different trees, II. *The Forest Floor, Journ. of Ecol.* 42, 1, 71-80.

Prusinkiewicz Z., Dziadowiec H., Jakubusek M., 1974. Zwrot do gleby pierwiastków – biogenów z opadem roślinnym w lesie liściastym i mieszanym na luźnych glebach piaskowych. (Return of nutrient-elements with the plant fall to soil in leafy and mixed forest on loose, sandy soils). *Rocz. Glebozn.*, XXV, 3, 106-122, (in Polish).

Puszkar L., Traczyk T., Wójcik Z., 1972. Primary production of herb laser and plant fall in the *Vaccinio myrtilli-Pinetum* forest association in the Pisz forest (NE Poland). *Ecol. Pol.* 20, 253-285.

Satoo T., Madgwick H. A. J., 1982. Forest biomass. Nijhoff and Junk Verlag, Haga, Boston, Londyn.

Sienkiewicz J., Małachowska. J., 1989. Charakterystyka opadu ścioły w gradzie i w borze. (Characteristic of the plant fall in hail and forest). W: Określenie stanu degradacji siedlisk leśnych oraz opracowanie ekologiczne podstaw ich degradacji. (Definition of the state degradiation for forest habilitats and elaboration of the ecological basis their degradation). (Ed.), Wolak J., Sienkiewicz J. IBL, Warszawa-Sękocin, (typescript).

Stachurski A., 1987. Nutrient control in throughfall waters of forest ecosystems. *Ecol. Pol.* 35, 1, 3-69.

Stachurski A., Zimka J. R., 1975. Leaf fall and the rate of litter decay in some forest habitats. *Ecol. Pol*., 23, 1, 103-108.

Stachurski A., Zimka J. R., 1984. The budget of nitrogen dissolved in rainfall during its passing through the clown canopy in forest ecosystems. *Ecol. Pol.* 32, 2, 191-218.

Tobolski K., Mocek A., Dzięciołowski W., 1997. Gleby Słowińskiego Parku Narodowego w świetle historii roślinności i podłoża. (Soils of Słowiński National Park in light of plants and substratum history). HOMINI, Bydgoszcz-Poznań, (in Polish).

Tyszka J., Wawrzoniak T., Janek M., 1998. Przepływ jonów przez ekosystemy borów świerkowych i sosnowych w różnych warunkach skażenia środowiska. (The flow of ions through ecosystems of fir and pine forests for different conditions of environment). *Prace Inst. Bad. Leś.*, A, 863-865, 35-57, (in Polish).

Wachowska-Serwatka K., 1966. Sezonowe zmiany azotu i składników mineralnych w ściółce, w glebie i w roślinach lasu mieszanego Rezerwatu Lubsza. (Seasonal changes of nitrogen and mineral components in litter, soil and plant of the mixed forest in Lubsza Reserve). *Acta Univ. Wratisl., Prace bot.* VII, 48, 71-160, (in Polish).

Wójcik J., 1970. Characteristic of organic fall collected in Kampinoski Primeval Forest. *Ecol. Pol.*, 18, 3, 87-95.

Zimka J. R., 1989. Analysis of processes of element transfer in forest ecosystems. *Pol. Ecol. Stud.* 15, 3-4, 135-212.

Zimka J. R., Stachurski A., 1976. Vegetation as a modifier of carbon and nitrogen transfer to soil in various types of forest ecosystems. *Ecol. Pol.*, 24, 4, 493-514.

OPAD ATMOSFERYCZNY I OPAD ROŚLINNY JAKO NATURALNE ŹRÓDŁA AZOTU I FOSFORU DLA GLEB LEŚNYCH W SŁOWIŃSKIM PARKU NARODOWYM

Streszczenie

Każdego roku gleby leśne wzbogacane są związkami azotu i fosforu pochodzącymi z opadających liści i igliwia, mineralizacji runa leśnego, gnijących korzeni drzew i krzaków oraz opadów atmosferycznych. Procesy te badano w dwóch ekosystemach leśnych Słowińskiego Parku Narodowego: w lesie mieszanym (działka I) i borze świeżym (działka II). Ogólny opad ścioły zebrany w świeżym borze wynosił 3,014 t $ha^{-1}rok^{-1}$ i był mniejszy niż zebrany w lesie mieszanym (4,346 t $ha^{-1}rok^{-1}$). Najbardziej intensywny opad ścioły obserwowano w miesiącach jesiennych i stanowił on odpowiednio 62,36% i 64,20% rocznego opadu. Ogólnie w ten sposób wprowadzono 46,96 kg $ha^{-1}rok^{-1}$ azotu i fosforu do gleby działki I i 22,04 kg $ha^{-1}rok^{-1}$ do gleby działki II. Opad atmosferyczny wzbogacił gleby lasu mieszanego w 33,66 kg $ha^{-1}rok^{-1}$ azotu i 1,19 kg $ha^{-1}rok^{-1}$ fosforu, a gleby boru świeżego odpowiednio 23,06 kg $ha^{-1}rok^{-1}$ i 0,92 kg $ha^{-1}rok^{-1}$.