Structure and accumulation of litterfall under Norway spruce stands in connection with thinnings

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ABSTRACT: The effect of thinning on the structure and accumulation of litterfall and hologranic horizons (L, F, H) in young Norway spruce stands was investigated. The research was conducted on a Norway spruce thinning experiment Polom (established in 1980) in the Orlické hory Mts. (north-eastern part of the Czech Republic). In 1992, the monitoring of litterfall started on an unthinned control stand (plot 1) and on a comparative stand with very heavy thinning from below (plot 3). During the period of observation (age of the stand 27–37 years), the total weight of litterfall ranged between 1,800 and 4,800 kg/ha. The amount of litterfall was partly influenced by climatic factors (precipitation and temperature), growth processes (basal area increment) and thinning regimes in individual years. The results of the investigations showed that dry biomass accumulated under a 36 years old Norway spruce stand ranged from 9,200 to 11,300 kg/ha in horizon L, from 37,000 to 38,200 kg/ha in horizon F and from 138,300 to 146,400 kg/ha in horizon H. The quality (content of basic nutrients) of litterfall and material from holorganic horizons are discussed.

Keywords: litterfall; nutrients; thinning; Norway spruce

Except for the climate (temperature and precipitation), the growing processes in forest stands are strongly influenced by nutrient supply. Thinning and cutting of forest stands, i.e. removing a part of forest biomass, are interventions in natural nutrient cycling in a forest ecosystem with consequences to health condition and wood- and non-wood-producing functions of forests.

In current productive forests, a dominant part of dead biomass mainly consists of leaves and needles. Therefore, we can regard biomass from litterfall as a principal nutrient source for forest stands. Even-aged Norway spruce (*Picea abies* [L.] Karst.) monocultures do not usually have any understorey and consequently spruce needle litterfall is important for the nutrient cycle. Furthermore, Norway spruce monocultures are regarded as conducive to degradation of forest soil condition. The main part of litter accumulation is a high fraction of hardly resoluble materials (resins, waxes and tannins) in spruce needles. MØLLER (1944) concluded on the basis of his studies in closed Norway spruce stands that the amount of needles was independent of: 1. stand age, 2. stand height, 3. site quality, and 4. thinning grade when measured several years after the last thinning. On the other hand, the effect of thinning on the quantity and quality of litterfall in Norway spruce stands was reported in many papers (ŠARMAN 1982a; VESTERDAL et al. 1995; CASTIN-BUCHET, ANDRE 1998, etc.).

The objectives of the study were to find out: 1. the characteristics of litterfall in young Norway spruce stands with different thinning regimes, 2. nutrient content of biomass from litterfall under young Norway spruce stands, 3. conceivable effect of thinning regimes on the quantity and quality of litterfall and holorganic horizons in young Norway spruce stands.

MATERIAL AND METHODS

The data were collected on a thinning experimental series Polom in the Orlické hory Mts. (north-eastern part of the Czech Republic) founded in 1980 in a 15 years old Norway spruce thicket. The stand lies on a 5% north-western slope, at an elevation of 800 m on Cambisol of the 6th Beech with Spruce Forest Vegetation Zone. Mean annual temperature is 5°C; the mean sum of precipitation amounts to ca. 1,000 mm. The co-ordinates of the series are 50°21´37´´N latitude and 16°19´33´´E longitude. The experimental stand was established by planting at irregular spacings with the initial density of 3,500–4,000 trees per hectare on a clear-cut area after spruce stands destroyed by snow (SLODIČÁK 1992). The thinning experiment is based on a traditional comparative method, i.e. on comparing the stands with different thinning regimes including the regime without thinning. Comparative plot 1 is a control plot without intentional thinning. Program 2 with heavy

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thinning with negative selection from below in five-year periods is tested on comparative plot 2 (not included in litterfall observations). Program 3 based on one very heavy low thinning at the young age and in longer periods is applied to the stand of comparative plot 3. The first experimental thinning on comparative plot 3 was carried out at the age of 15 years (in 1980) and the second low thinning was done at the age of 30 years (1995).

The litterfall observations started in 1990 when 16 collectors of the area 0.5 m^2 each were installed (NOVÁK, SLODIČÁK 2000). Half of them (8 collectors) was placed on unthinned control stand (plot 1) and the second half on comparative stand with very heavy thinning from below on plot 3. Collectors were placed on both plots in transects with regular spacing (4 m) in order to get the representative situation of canopy on comparative plot including incidental irregularities. Litter was collected weekly in the first two years, later monthly. Samples from particular collectors were dried first in the open air and afterwards in a laboratory at 105°C and weighed. Nutrient content was assessed monthly from composite samples from each comparative plot (after mineralisation by mineral acids). Total nitrogen (N) concentration was analysed by Kjeldahl procedure and phosphorus (P) concentration was determined colorimetrically. An atomic absorption spectrophotometer was used to determine total potassium (K) concentration by flame emission, and calcium (Ca) and magnesium (Mg) by atomic absorption after addition of La.

In 2001, holorganic horizons (litter – L, fermentation – F, humus – H) were investigated quantitatively and qualitatively on identical comparative plots. A steel frame 25 × 25 cm was used for sampling at three replications in October 2001. Samples from each horizon were dried first in the open air and afterwards in a laboratory at 105°C and weighed. Nutrient content was assessed from composite samples from each replication (after leaching by citric acid). Total N, P, K, Ca and Mg concentrations were analysed by the above-mentioned procedures (the same as litterfall samples).

All statistical analyses were performed in statistical system UNISTAT® (version 5.1) using the significance confidence level of 0.95. Data sets (amount of dry biomass, nutrient contents) were tested by parametric tests (*t*-test). Pearson's correlation coefficients (*r*) were calculated to assess the relationship between annual amount of litterfall (dry biomass) and a) climatic factors (precipitation, temperature) and b) basal area increment.

RESULTS

Total amount of dry biomass of litterfall

Total weight of litterfall ranged from 1,800 to 4,800 kg/ha (Fig. 1) during the eleven-year period of observation (stand age 27–37 years). At the beginning of the experiment, in 1992, ca. 2,800 kg of biomass per hectare fell on control plot 1 (without thinning). Total amount of litterfall increased in the following years and in 1996 (age 31 years) the maximum (4,800 kg/ha) was recorded. In the next year, the amount of litterfall on control plot noticeably decreased. From 1998

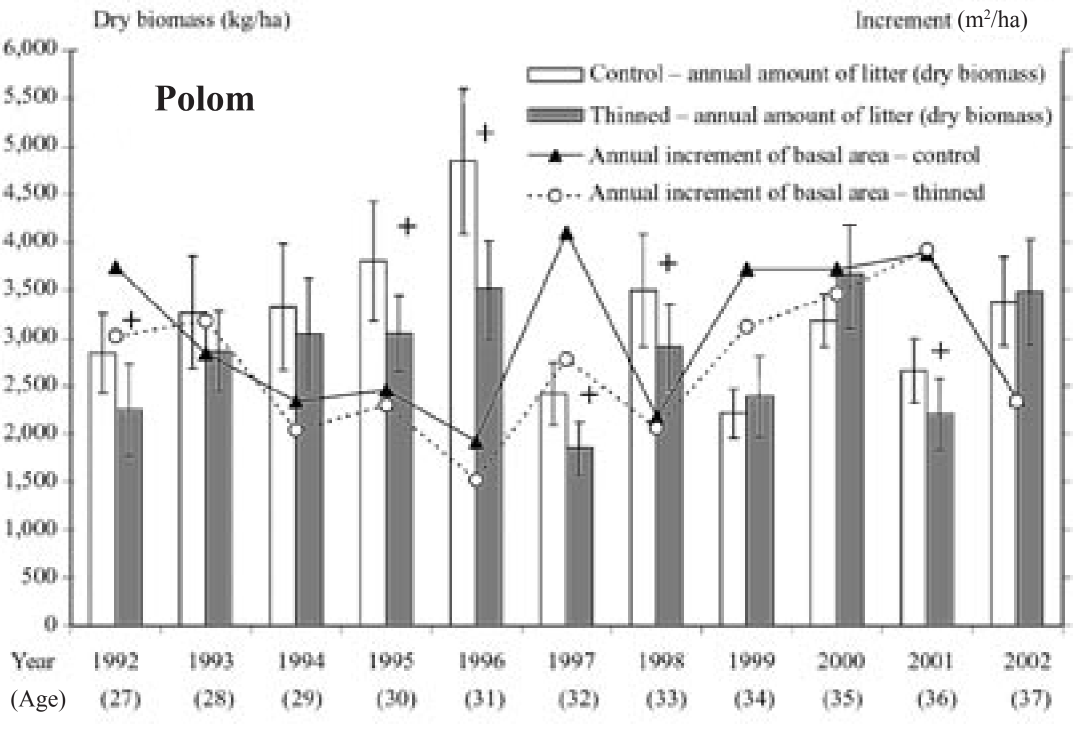

Fig. 1. Annual amount of litterfall (dry biomass in kg/ha) with standard deviations (*Sx*) on unthinned control stand (plot 1) and on heavily thinned stand (plot 3) of experimental Norway spruce series Polom in the Orlické hory Mts. in 1992–2002 (age 27–37 years). The amount of litterfall can be influenced by annual basal area increments (lines). Statistically significant differences between thinning variants were marked by +

Table 1. The results of correlation analyses (Pearson's correlation coefficients). Relationships between annual amount of litterfall (dry biomass) and climatic factors (precipitation, temperature) and basal area increment (significant coefficients are in bold)

Index		Annual amount of litter (dry biomass)	
		control	thinned
Amount of precipitation	May	**0.57**	0.27
	August	0.29	**0.60**
Mean temperature	April	0.41	**0.78**
	September	**–0.76**	–0.40
	Spring season*	0.20	**0.66**
Annual increment of basal area		**–0.83**	–0.44

*period from April to June

to 2002, the annual amount of litterfall oscillated (in 1998, 2000, 2002 – increase and in 1999, 2001 – decrease) and the minimum (2,200 kg/ha) was found in 1999.

On thinned plot 3 (very heavy thinning from below), a similar tendency of litterfall amount is apparent. However, from 1992 to 1998, the annual amount of litterfall on thinned plot was always lower than the amount on control plot. These differences were statistically significant in 1992, 1995, 1996, 1997 and 1998. On the other hand, in 1999, 2000 and 2002, the annual amount of litterfall on thinned plot was higher than on control plot, but the differences were found statistically insignificant. The only exception of the last years is the situation in 2001, which showed a higher annual amount of litterfall on control plot than on the plot with thinning (significant difference).

In the subsequent phase of investigation, causes of the trend and differences in the annual amount of litterfall were established. The results of correlation analysis showed that the total annual weight of litterfall was influenced mostly by climatic factors (precipitation and temperature). Significant correlations between annual amount of litterfall and monthly amount of precipitation were founded on control plot in May and on thinned plot in August (Table 1). Annual weight of litterfall was significantly influenced by mean temperature in September on control plot (negative correlation) and in April and in the spring season (April–June) on thinned plot.

Growth processes might be another factor that influenced the annual amount of litterfall. The negative correlation between annual amount of litterfall and annual increment of basal area was investigated on both comparative plots. This means that a lower annual amount of litterfall was detected in periods (years) characterised by a higher annual increment of basal area. However, this relation was statistically significant only on control plot.

Differences between the variants (control and thinned) of the experiment were significant in the period 1995 to 1998, partly because of thinning regime. Negative selection from below (26% of trees removed) was made in 1995 on plot 3 (thinned). Removed biomass on thinned stand was compensated by 1999 (three years after thinning). Significant differences between the variants in 1992 were probably caused by heavy rime in winter. Rime damage was higher on thinned plot 3 because dominant trees with great dimensions of green crowns are the most endangered by rime. A similar situation was detected after winter 2001/2002, when control (mainly thin trees from below) was damaged by snow and probably therefore no significant differences in the annual amount of litterfall between the variants in 2001 were found in 2002.

Total amount of dry biomass of humus horizons

Holorganic horizons (litter – L, fermentation – F, humus – H) were investigated on both comparative plots (control – 1, thinned – 3). Fig. 2 shows that dry biomass accumulated in horizon L (litter) under 36 years old Norway spruce stand ranged from 9,200 to 11,300 kg per hectare. The annual amount of litterfall ranged from 1,800 to 4,800 kg/ha in experimental spruce stands (see above). This means that horizon L contained biomass of 2–4 years litterfall. In the second horizon F (fermentation), 37–38 thousand kg of dry biomass per hectare are stored. Most of dry biomass (more than 140 thousand kg per hectare) is accumulated in horizon H (humus). The differences between the thinning variants in accumulated dry biomass are statistically insignificant for all horizons L, F and H.

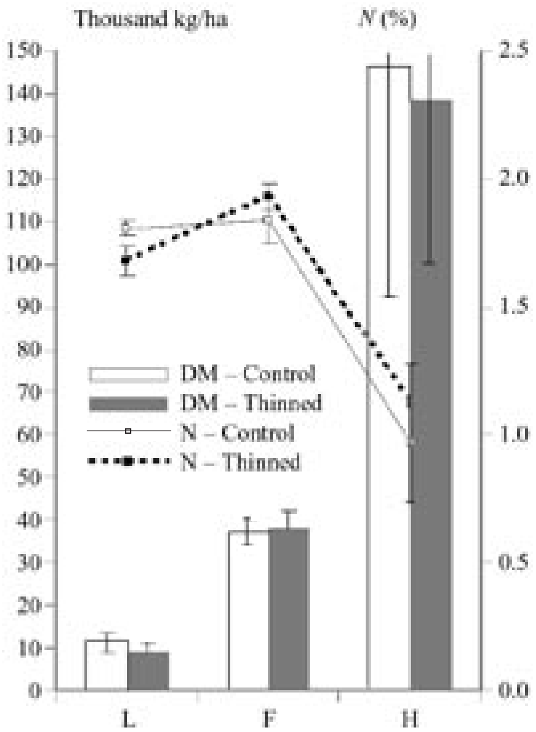

Fig. 2. Amount of dry biomass (DM) and nitrogen (N in %) in holorganic L (litter), F (fermentation) and H (humus) horizons with standard deviations (*Sx*) on unthinned control stand and on heavily thinned stand of experimental Norway spruce series Polom in the Orlické hory Mts. in 2001 (age 36 years)

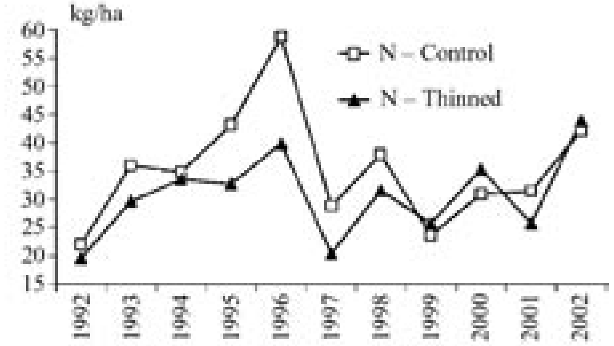

Fig. 3. Annual amount of nitrogen in litterfall (kg/ha) on unthinned control stand and on heavily thinned stand of experimental Norway spruce series Polom in the Orlické hory Mts. in 1992–2002 (age 27–37 years)

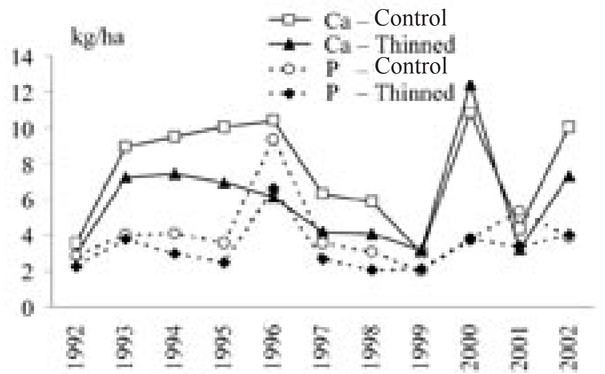

Fig. 4. Annual amount of calcium and phosphorus in litterfall (kg/ha) on unthinned control stand and on heavily thinned stand of experimental Norway spruce series Polom in the Orlické hory Mts. in 1992–2002 (age 27–37 years)

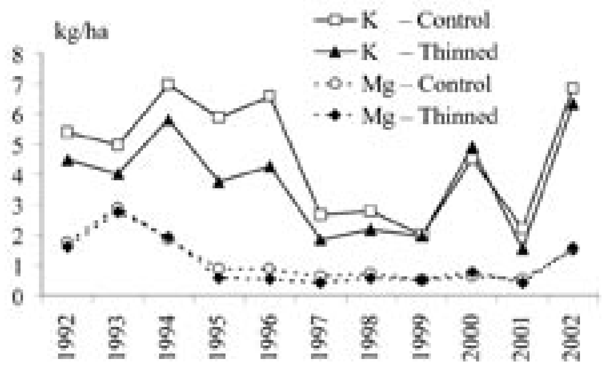

Fig. 5. Annual amount of potassium and magnesium in litterfall (kg/ha) on unthinned control stand and on heavily thinned stand of experimental Norway spruce series Polom in the Orlické hory Mts. in 1992–2002 (age 27–37 years)

Nutrient content of litterfall

The results of investigation showed that biomass from litterfall contained about 1% of N. It means that the annual return of N represented 20–60 kg N per hectare on control unthinned plot and 20–45 kg N per hectare on thinned plot (Fig. 3). The percentage of Ca and P in litterfall was rela-

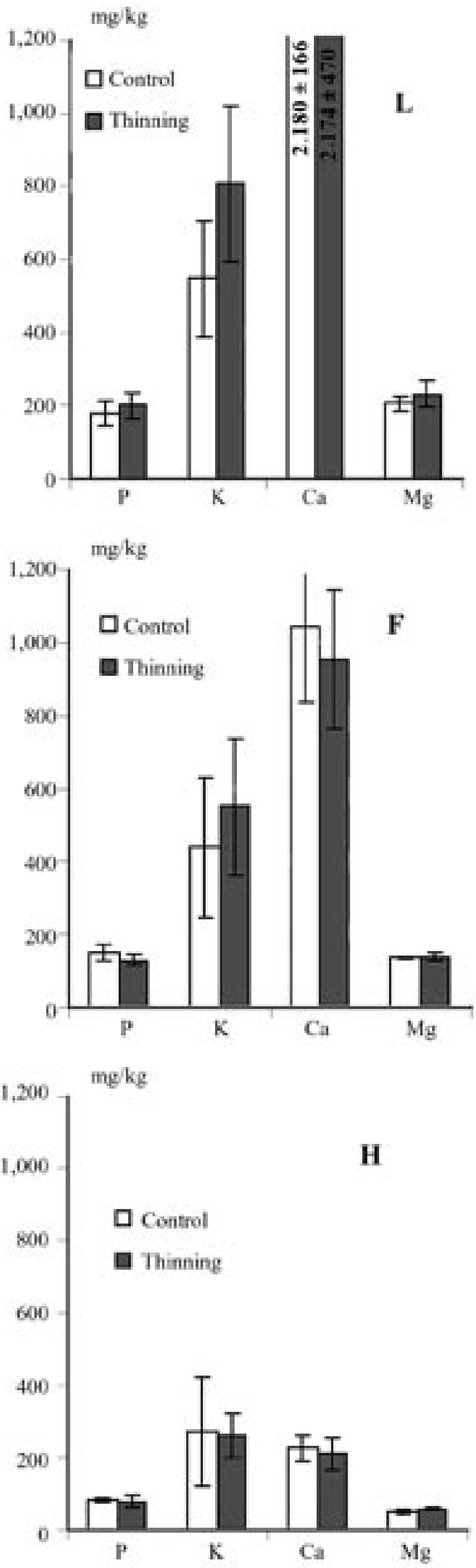

Fig. 6. Amount of P, K, Ca and Mg (with standard deviations) in holorganic horizons (L, F, H) on unthinned control stand and on heavily thinned stand of experimental Norway spruce series Polom in the Orlické hory Mts. in 2001

tively constant during the period 1992–1997. Therefore the total amount (kg per hectare) of these nutrients depended on total dry weight of litterfall in particular years (Fig. 4). In 1998 the annual amount of litterfall increased, but Ca and P content in litterfall decreased. This trend was reduced in the following years. In the period 2000–2002, the total amount of Ca markedly varied (from 3 to 12 kg/ha). The trend of P amount in litterfall was similar during the period of observation (Fig. 5). On the other hand, the total amount of magnesium did not depend on total dry weight of litterfall and since 1993 it has shown a decreasing tendency. This continually diminishing content of Mg in litterfall may signalise its gradual exhaustion from the cycle of nutrients in the investigated forest ecosystem. In 2002, Mg content of litterfall increased on both comparative plots (Fig 5).

Nutrient content of humus horizons

According to the used methods, holorganic horizons (litter – L, fermentation – F, humus – H) were investigated quantitatively and qualitatively on identical comparative plots in 2001. The material from humus horizons contained from 1 to 2% of nitrogen (Fig. 2). Content of nitrogen is similar in horizons L and F (about 1.8%), but in horizons H only about 1% of N was detected. Differences between the comparative variants were statistically significant only in horizon L (1.8% of N on control and 1.7% on thinned plot).

The highest content of monitored nutrients was found in horizon L. The material from horizon L contains about 180–200 mg/kg of P, 550–800 mg/kg of K, 2,170 to 2,180 mg/kg of Ca and 200–230 mg/kg of Mg (Fig. 6). Similar proportions of nutrients (but lower values) were detected in horizon F (about 130–150 mg/kg of P, 440 to 550 mg/kg of K, 950–1,040 mg/kg of Ca and 140 mg/kg of Mg). The higher Ca content in both horizons was partly influenced by aerial liming (dolomitic limestone) that was applied in the Orlické hory Mts. one year before sampling (in 2000). On the other hand, this phenomenon was not found in horizon H. The lowest content of monitored nutrients was determined in horizon H (about 80 mg/kg of P, 260–270 mg/kg of K, 210–230 mg/kg of Ca and 50 to 60 mg/kg of Mg). The results of statistical analyses showed that differences between the values of nutrient (P, K, Ca, Mg) content on both comparative plots (control and thinned) were not significant.

DISCUSSION

Total amount of litterfall increased in the first period of observation and the maximum (4,800 kg/ha) was recorded in 1996 (age 31 years). This peak occurred in accordance with the culmination of green needle biomass growth. The period between the age 20 and 25 years is indicated by CHROUST (1993) as the maximum growth of green needle biomass in young spruce stands. In Polom experiment (Eastern Czech Republic), the annual amount of litterfall ranged from 1,800 to 4,800 kg/ha during the period of observation (the stand age of 27–37 years). Similar results were reported by BILLE-HANSEN, HANSEN (2001) in forty years old Norway spruce stands. The foliar litterfall at Ulborg, Lindet and Frederiksborg (Danish experiments with Norway spruce) ranged from 1,100 to 5,700 kg/ha between the years.

The results of presented analyses showed that the total annual weight of litterfall was influenced by climatic factors (precipitation and temperature). The annual weight of litterfall was significantly influenced by mean temperature in April and in the spring season (April–June) on thinned plot. Warm spring might probably be an important factor that positively influences the annual amount of litterfall. On the other hand, a negative correlation between annual weight of litterfall and mean temperature in September was found. It probably means that the vegetation period is prolonged by a higher temperature in September and green biomass can be active longer.

In the present study it was detected that the annual amount of litterfall was negatively influenced by an annual increment of basal area (the relation was statistically significant only on control plot). It is in contrast with the results of HOLSTENER-JØRGENSEN et al. (1979), who

Table 2. A comparison of the amount of nutrients in litterfall during the period 1998–2001 and in horizon L in 2001 on the Norway spruce thinning experiment Polom in the Orlické hory Mts.

Nutrients (kg/ha)		Ca		Mg		K		P	
		control	thinned	control	thinned	control	thinned	control	thinned
Amount in litterfall	1998	5.86	4.07	0.73	0.57	2.80	2.18	3.06	2.03
	1999	2.99	3.17	0.50	0.51	1.99	1.97	1.94	2.09
	2000	10.82	12.39	0.65	0.79	4.52	4.91	3.76	3.77
	2001	4.35	3.23	0.55	0.42	2.22	1.54	5.32	3.38
	Total 1998–2001 (A)	24.02	22.86	2.43	2.29	11.53	10.60	14.08	11.27
Amount in horizon L in 2001 (B)		24.63	20.00	2.32	2.13	6.19	7.43	2.05	1.83
B as part of A (%)		**103**	**87**	**95**	**93**	**54**	**70**	**15**	**16**

found out a positive correlation between the amount of litterfall and basal area increment in a 21 years old Norway spruce stand. On Polom experiment, the annual amount of litterfall was probably influenced also by air pollution damage that culminated in this region in the eighties.

WILHELMI (1988) reported that the amount of litterfall in 40–50 years old Norway spruce stands was influenced by thinning. This effect of thinning on litterfall amount was observed on Polom experiment. Differences between the variants (control and thinned) of the experiment were significant in 1995–1998. Negative selection from below (26% of trees removed) was carried out on plot 3 (thinned) in 1995 and the removed biomass of the thinned stand was compensated by 1999 (three years after thinning).

Presented results showed that dry biomass accumulated in horizon L (litter) under the 36 years old Norway spruce stand ranged from 9,200 (thinned plot) to 11,300 (control plot) kg per hectare. PODRÁZSKÝ (1996) found in this experiment (Polom) that the amount of dry biomass accumulated in horizon L on thinned plot was from 7,710 kg/ha to 9,230 kg/ha (sampling took place in November 1993). It means that an increase in dry biomass amounting to about two thousand kg per hectare was detected in horizon L on both comparative plots during the eight-year period (1993–2001). In the period 1994–2001, total weight of litterfall ranged from 1,800 to 4,800 kg/ha. Therefore we can say that the accumulation of litter under 30 years old Norway spruce monoculture is not so enormous. Similar results (amount of dry biomass in horizon L from 7,340 to 8,870 kg/ha) were found by ŠARMAN (1982b) in fifty years old Norway spruce stands in the Czech-Moravian Uplands.

It was found on Polom experiment that the annual return of N through litterfall amounted to 20–60 kg N per hectare on unthinned control plot and 20–40 kg N per hectare on thinned plot. It corresponds with the data published by KLIMO and KULHAVÝ (1994) – 43 kg N/ha/y and GUNDERSEN and RASMUSSEN (1995) – 37 kg N/ha/y.

The material from humus horizons contained from 1 to 2% of nitrogen. On the other hand, dry biomass from litterfall contained only about 1% of N. Nitrogen flows did not depend on litterfall input only. Complete deposition and other flows of N (in bulk precipitation, throughfall, etc.) were monitored by GUNDERSEN (1995). Therefore, more detailed research on N deposition will be the next step of nutrient cycling investigations on Polom experiment.

In the period 2000–2002, the total amount of Ca in litterfall markedly varied and increased from 3 to 12 kg/ha (300% increment) during one year, while total amount of litterfall increased 40% only. Ca content was partly influenced by aerial liming (dolomitic limestone) that was applied in the Orlické hory Mts. in 2000 and 2002. Similarly like Ca content in litterfall, the higher Ca content in horizons L and F (in 2001) was probably influenced by aerial liming, but this phenomenon was not observed in horizon H.

Possible influence of liming on total amount of Mg in litterfall (in dolomitic limestone as MgO) was found in 2002 only. This continually low content of Mg in litterfall may signalise its gradual exhaustion from the cycle of nutrients in the investigated forest ecosystem.

The results of investigations showed that dry biomass accumulated in horizon L (litter) under the 36 years old Norway spruce stand ranged from 9,200 to 11,300 kg per hectare and annual amount of litterfall ranged from 1,800 to 4,800 kg/ha. This means that horizon L contained biomass of 2–4 years litterfall. It can correspond with the total amount of individual nutrients (Ca, Mg, K, and P) during the period 1998–2001. Table 2 shows that this hypothesis was confirmed only for Ca, Mg and partly for K. On the other hand, dry biomass in horizon L contains only about 15% of the total amount of phosphorus in litterfall during the period 1998–2001. This agrees with the results of PRESCOTT et al. (1993) that phosphorus is released from litter immediately.

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Struktura a akumulace opadu pod smrkovými porosty ve vztahu k výchovným zásahům

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ABSTRAKT: Na experimentální řadě Polom v Orlických horách (založené v roce 1981) byl sledován efekt výchovy na strukturu a akumulaci opadu a holorganických horizontů (L, F, H) v mladých smrkových porostech. Opadové poměry byly monitorovány od roku 1992 na dílčí ploše bez výchovy (plocha 1) a na ploše se silnými podúrovňovými zásahy (plocha 3). Ve sledovaném období (věk porostu 27–37 let) se celkový roční opad pohyboval mezi 1 800 až 4 800 kg/ha. Množství opadu bylo zčásti ovlivňováno klimatickými faktory (průběh srážek a teplot), růstovými procesy (přírůst výčetní kruhové základny) a výchovnými zásahy v jednotlivých letech. Pod 36letým smrkovým porostem je akumulováno v horizontu L 9,2 až 11,3 tun sušiny na hektar. V horizontu F bylo zjištěno 37,0 až 38,2 tun a v horizontu H 138,3 až 146,4 tun sušiny na hektar. V práci jsou diskutovány výsledky kvalitativních rozborů (obsahy základních živin) biomasy v opadu a v jednotlivých humusových horizontech.

Klíčová slova: opad; živiny; výchova; smrk ztepilý

V současných produkčních lesích tvoří hlavní část opadávané biomasy listí a jehličí. Lze proto říci, že navracená biomasa z opadu patří mezi důležité zdroje živin pro lesní porosty. Hlavním zdrojem živin je opadávané jehličí zejména ve stejnověkých monokulturách smrku ztepilého (*Picea abies* [L.] Karst.), kde obvykle chybí spodní etáž (podrost). Cílem práce bylo zjistit: 1. jaká je charakteristika opadu v různě vychovávaných mladých porostech smrku ztepilého, 2. jaký je podíl živin v opadávané biomase v mladých smrkových porostech, 3. jak je kvantita a kvalita opadu a ukládané biomasy v humusových horizontech ovlivňována výchovou.

Výzkum probíhal na experimentální řadě Polom v Orlických horách, která byla založena v roce 1980 v 15leté smrkové mlazině, ležící na mírném (5%) svahu se SZ expozicí na kambizemi v nadmořské výšce 800 m (SLT 6K). Průměrná roční teplota je 5 °C a průměrný roční úhrn srážek činí 1 000 mm. Zeměpisné souřadnice lokality jsou 50°21´37´´ severní šířky a 16°19´33´´ východní délky. Porost vznikl z výsadby čtyřletých obalovaných sazenic v roce 1965 v původní hustotě 3,5 až 4 tisíce jedinců na hektar. Série je tvořena třemi srovnávacími plochami o velikosti 40 × 25 m (SLODIČÁK 1992). Srovnávací plocha 1 je ponechána jako kontrolní, tj. bez úmyslných těžebních zásahů. Porost na srovnávací ploše 2 je vychováván podle programu navrženého pro porosty ohrožené abiotickými činiteli a není zahrnut do vyhodnocení v rámci této práce. Na srovnávací ploše 3 je na obou sériích uplatňován výchovný režim založený na velmi silných zásazích s negativním výběrem v podúrovni. První zásah byl na srovnávací ploše 3 proveden ve věku porostu 15 let (v roce 1980) a druhý ve věku 30 let (v roce 1995).

Sledování opadových poměrů bylo zahájeno v roce 1990, kdy bylo instalováno celkem 16 kolektorů (8 kusů na variantu 1 bez výchovy a 8 kusů na variantu 3 se silnými podúrovňovými zásahy), každý se záchytnou plochou 0,5 m² (NOVÁK, SLODIČÁK 2000). Opadoměry byly vybírány zpočátku v měsíčních, později ve čtvrtletních intervalech. Po každém odběru byla laboratorně zjišťována hmotnost sušiny (105 °C) a ze směsného vzorku (pro každou variantu zvlášť) byly stanoveny podíly živin (N, P, K, Ca, Mg). V říjnu roku 2001 byly pomocí kovových rámečků (25 × 25 cm) odebrány vzorky humusových horizontů (L, F, H – ve třech opakováních na každé variantě) pro kvantitativní a kvalitativní analýzu. Podobně jako u opadu byly stanovovány hmotnost sušiny a podíl jednotlivých živin. Statistické analýzy zjištěných dat byly prováděny pomocí statistického softwaru UNISTAT® (verze 5.1) na zvolené hladině významnosti 0,95.

Ve sledovaném období (věk porostu 27–37 let) kolísalo roční množství opadu od 1 800 do 4 800 kg/ha (obr. 1).

Na kontrolní variantě bez zásahu byly maximální hodnoty (4 800 kg/ha) zjištěny v roce 1996 (věk 31 let) a minimální o tři roky později v roce 1999 (2 200 kg/ha). Na variantě s výchovou (silné podúrovňové zásahy) byl zaznamenán podobný trend, avšak v období 1992–1998 byl objem opadávané biomasy vždy nižší než na kontrolní ploše. Zjištěné rozdíly byly statisticky průkazné v letech 1992 a 1995–1998. Naproti tomu v letech 1999, 2000 a 2002 byl roční opad vyšší na ploše s výchovnými zásahy (bez statistické průkaznosti). Výjimkou byl rok 2001, kdy byl zaznamenán průkazně vyšší objem opadávané biomasy na kontrolní ploše.

Podle výsledků korelační analýzy byl celkový objem opadávané biomasy ovlivněn klimatickými faktory (průběh srážek a teplot). Průkazné vztahy byly zaznamenány mezi množstvím ročního opadu a měsíčním úhrnem srážek v květnu (na kontrolní ploše) a v srpnu (na ploše s výchovnými zásahy). Dále byla zjištěna signifikantní závislost množství ročního opadu v kontrolním porostu na průměrné měsíční teplotě v září (negativní korelace) a ve vychovávaném porostu na průměrné měsíční teplotě v dubnu a průměrné teplotě v období duben–červen (tab. 1). Dalším faktorem ovlivňujícím množství ročního opadu jsou zřejmě růstové procesy. Byla zjištěna negativní korelace ve vztahu ročního objemu opadávané biomasy k ročnímu přírůstu výčetní kruhové základny, a to na obou variantách pokusu (na zvolené hladině významnosti je uvedený vztah statisticky průkazný pouze na kontrolní variantě).

Efekt výchovy na množství opadávané biomasy byl na experimentální řadě Polom statisticky průkazně doložen v období 1995–1998. Výchovný zásah na variantě 3 (odebráno 26 % počtu stromů negativním výběrem v podúrovni) byl proveden v roce 1995. Odstranění biomasy ve vychovávaném porostu tak bylo kompenzováno až tři roky po zásahu v roce 1999, kdy se množství ročního opadu na obou variantách průkazně nelišilo (obr. 1). V roce 1992 byly signifikantní rozdíly mezi variantami v hodnotách ročního opadu způsobeny zřejmě poškozením porostu zimní námrazou. Vyšší škody (korunové zlomy) byly zaznamenány na variantě 3 s výchovou, protože námraza postihuje v těchto lokalitách dominantní stromy s velkou zelenou korunou. Podobná situace byla zaznamenána po zimním období 2001/2002, kdy byl poškozen kontrolní porost sněhem (zejména tenké stromy z podúrovně). Zřejmě z tohoto důvodu nebyly rozdíly v hodnotách ročního opadu zjištěné mezi variantami v roce 2001 potvrzeny v roce 2002.

Bylo zjištěno, že biomasa akumulovaná v horizontu L pod 36letým smrkovým porostem představuje na jeden hektar 9 200 (porost s výchovou) až 11 300 (kontrolní porost) kg sušiny (obr. 2). Podle zjištění, že ve sledovaném porostu ročně opadává od 1 800 do 4 800 kg/ha, obsahuje horizont L dvouletý až čtyřletý opad. V horizontu F bylo zjištěno 37,0–38,2 tun a v horizontu H 138,3–146,4 tun sušiny na hektar. Rozdíly mezi variantami pokusu v množství akumulované sušiny nebyly statisticky potvrzeny u žádného z vyšetřovaných horizontů.

Podle výsledků kvalitativních analýz obsahuje opadávaná biomasa okolo 1 % dusíku. Každoročně je tak touto formou navraceno na hektar 20–60 kg dusíku na kontrolní ploše bez výchovy a 20–45 kg dusíku na ploše s výchovnými zásahy (obr. 3). Obsah vápníku a fosforu v opadu byl v letech 1992–1997 relativně konstantní, a tak bylo ročně navracené množství těchto živin (kg/ha) přímo závislé na celkovém objemu biomasy opadávané v jednotlivých letech (obr. 4). V období 2000–2002 se množství vápníku v opadu meziročně zvýšilo o 300 % (ze 3 na 12 kg/ha), zatímco celkový objem opadávané biomasy se zvýšil pouze o 40 %. Důvodem je zřejmě letecké vápnění (dolomitickým vápencem), které bylo aplikováno v Orlických horách v letech 2000 a 2002. Předpokládaný efekt na celkové množství hořčíku (v dolomitickém vápenci ve formě MgO) byl zaznamenán pouze v roce 2002 (obr. 5).

Pod vyšetřovaným smrkovým porostem bylo nejvíce živin akumulováno v horizontu L (180–200 mg/kg fosforu, 550–800 mg/kg draslíku, 2 170–2 180 mg/kg vápníku a 200–230 mg/kg hořčíku). Podobný poměr živin (avšak nižší hodnoty) byl zjištěn v horizontu F (130–150 mg/kg fosforu, 440–550 mg/kg draslíku, 950–1 040 mg/kg vápníku a 140 mg/kg hořčíku). Nejnižší hodnoty obsahu živin byly zaznamenány v horizontu H (80 mg/kg fosforu, 260–270 mg/kg draslíku, 210–230 mg/kg vápníku a 50–60 mg/kg hořčíku). Rozdíly mezi variantami pokusu (kontrolní a s výchovou) v obsahu živin ve vyšetřovaných humusových horizontech byly statisticky neprůkazné (obr. 6).

Podle našich šetření tedy obsahuje horizont L pod sledovaným 36letým smrkovým porostem dvouletý až čtyřletý opad (odběr vzorků v r. 2001). V horizontu L by podle tohoto zjištění měly být akumulovány obsahy jednotlivých živin (Ca, Mg, K, P) za období 1998 až 2001. Tento předpoklad byl potvrzen pouze u vápníku a hořčíku a částečně u draslíku (tab. 2). U fosforu bylo zaznamenáno okamžité uvolňování z biomasy akumulované v tomto horizontu. V roce 2001 obsahoval tento horizont pouze 15 % celkového množství této živiny navracené formou opadu za období 1998–2001. Výzkumná šetření jsou prováděna v rámci dlouhodobého výzkumného záměru Ministerstva zemědělství MZE-M06-99-01.

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