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ORIGINAL PAPER

Litterfall nutrient return in thinned young stands with Douglas fir

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Abstract
The use of Douglas fir (DF) is on the increase in the Czech Republic. This tree species shows a good production and also a beneficial impact on soil to some extent. We studied both amount and properties of litterfall in 18 to 20-year-old stands with DF in 2011. Two experimental plots were DF-dominated and one showed ca. 20 – 30% share of Scots pine (SP) at the beginning of observation. The experiments consisted of two treatments such as unthinned control and 50 – 62% trees' density reduction accounting for 43 – 59% basal area reduction. Litterfall was collected using litter traps of 0.25 m^2 area in 3 – 4 traps per treatment. Forest floor L and F were taken in 2011 and 2018 to investigate the development of their amount after thinning. Both whole-period sum and mean annual litterfall were reduced after thinning compared to controls. The mean annual litterfall totaled ca. 3 t ha^{-1} in 20-year-old DF–dominated stands. This amount represents an annual nutrient return of 30 – 40 kg N, 1 – 3 kg P, 3 – 5 kg K, 12 – 30 kg Ca and 1 – 2 kg Mg per one hectare. The reduction of the annual litterfall was more pronounced in DF–dominated stands. All thinned plots showed increased decomposition rates reflected in lower total L+F amounts in both DF–dominated plots whereas unthinned plots accumulated more L+F at the end. The mixed DF–SP plot showed reduced L and increased F layer amounts in both unthinned and thinned treatments with only minor change to L+F sum between 2011 and 2018.

Key words: litterfall; forest floor; thinning; nutrients; Douglas fir

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1. Introduction

Forest ecosystems face both climate changes and various levels of anthropogenic disturbance. At many sites, Norway spruce stands exhibit a die-off due to lack of precipitation and following bark beetle outbreak. Foresters are, therefore, forced to find new silviculture approaches frequently; for example tree species conversion. At many sites, domesticated non-native trees such as Douglas fir (hereinafter referred to as DF), which have proved their capabilities, are beneficial. Although DF has been connected with central European forestry for more than hundred years, only several thousand hectares are managed (0.28% of current species composition) in the Czech Republic. This situation is likely to be attributable to fear of wider use of non-native tree species. However, the risk of wrong decision is minimized by intensive research and long-term verification of recommended silvicultural measures in forest practice in the last decades.

Besides its outstanding production (Kantor et al. 2001; Podrázský et al. 2013), also soil improving effects of litterfall were observed (Thomas & Prescott 2000; Podrázský & Remeš 2005, 2008; Podrázský & Kupka 2011; Ulbrichová et al. 2014) compared to other conifers. Although some information on accumulation and decomposition of DF litterfall have been published (Menšík et al. 2009; Podrázský et al. 2009), long-term investigation into year-by-year amounts and quality of litterfall including its relation to thinning were needed. In the Czech Republic, the use of DF is a rising issue which is reflected in number of projects (Kubeček et al. 2014; Slodičák et al. 2014) and resulted in establishment of many experimental plots. Thinning improves stands' stability (e.g. Settineri et al. 2018) and reduces stress resulting from overstocking (Chase et al. 2016) which can lead to a greater mortality during the decline events such as drought (Livingston & Kenefic 2018). Thinning can also help improve microbial conditions in organic horizons such as L and F (Wang et al. 2019).

The objectives of this study was to monitor litterfall amounts changes after thinning and analyze its nutrient contents in order to estimate an impact of thinning on nutrient return over longer time compared to previously published studies.

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2. Material and methods

Three thinning experiments with DF were established in spring 2011 (Table 1) in 18 to 20-year-old stands. DF dominated in the species compositions totally (Obo) or other species were admixed – mainly Norway spruce or Scots pine in the experiment Pol1 or Pol2, respectively. Stands were established by artificial (Obo) and natural (Pol1 and Pol2) regeneration. All sites are located in the Eastern part of Bohemia and belong to Colloredo-Mansfeld family estate. Mean annual temperature is 9.6 °C and mean annual amount of precipitation is 520 mm in the region of interest.

Each experiment consisted of two plots (with area of 0.04 ha), one was control unthinned stand and second one was managed using a very heavy thinning from below (Fig. 1). Thinning intensity was 62% on the basis of number of trees (N) and 59% on the basis of removed basal area (G) in Pol1. Two thinnings were done in Pol2. First at the start of observation period (50% of N and 49% of G removed) and second was realized 7 years later at the age of 24 years (24% of N and 43% of G removed). On the experiment Obo, 57% of N representing 43% of G was removed by first thinning at the age of 20 years.

Litterfall was collected using 3 – 4 litter traps (with an area of 0.25 m^2 each) per partial plots installed within stands in February (Obo) and October (Pol1, Pol2) 2011. The samples were taken twice to fourth times per year until October 2018.

At both the beginning (autumn 2011) and the end (autumn 2018) of observation period, forest-floor humus horizons (data from L = fresh litter and F = fermented layer were analyzed in this study) were investigated quantitatively in comparative plots (C – control and T – thinned) of all experiments. The samples were taken using steel frames (25 × 25 cm) to demarcate an area for collecting all enclosed material. Comparative plots and also observed stands are relatively small and homogenous. Nevertheless, the number of samples was gradually increased (three samples per plot in 2011 and six samples per plot in 2018).

All samples were dried, first under conditions of open air, later in a laboratory oven at 80 °C, and dry samples were subsequently weighed. Nutrient content in litterfall was assessed from composite samples from each comparative plot (after mineralization by mineral acids). Total nitrogen concentration was analyzed using Kjehldahl procedure and phosphorus concentration was determined colorimetrically. An atomic absorption spectrophotometer was used to determine total potassium concentration by flame emission, and calcium and magnesium by atomic absorption after addition of lanthanum. Data were analyzed using a descriptive statistics and we use paired t-test for total litterfall samples from three control and thinned plots.

Table 1. Characteristics of experimental plots at the start (2011) and at the end (2018) of litterfall observation by number of trees (N) and by basal area (G).

Plot	Abbreviation	Coordinates	Elevation slope, aspect	Soil	Site*	Year	Age [years]	Species composition [%] by N						Species composition [%] by G					
								DF	NS	SP	OK	BI	EL	DF	NS	SP	OK	BI	EL
Polanky 1 – Control	Pol1 C	50.205924	260 m			2011	18	80	18	1	0.5	0.5		82	14	1	2	1	
			10°	dystric cambisol on gravel-sand sediment	Fageto – Quercetum	2018	25	80	17	1.5	0.8	0.7		77	18	2	2	1	
Polanky 1 – Thinned	Pol1 T	16.028731	WSW		cidophilum	2011	18	88	9	3				96	4	0			
						2018	25	89	11					95	5				
Polanky 2 – Control	Pol2 C	50.20615	265 m			2011	18	74	3	23				55	3	42			
			10°	dystric cambisol on gravel-sand sediment	Fageto – Quercetum	2018	25	66	3	31				32	3	65			
Polanky 2 – Thinned	Pol2 T	16.028933	WSW		acidophilum	2011	18	51	2	47				35	1	64			
						2018	25	55	3	42				35	1	64			
Obora – Control	Obo C	50.24797	345 m	dystric cambisol on sandy marlstones	Querceto – Fagetum	2011	20	89	11					98	2				
			6°	to spongilitic, sporadically silicificated	illimerosum trophicum	2018	27	100						100					
Obora – Thinned	Obo T	16.119434	WNW	claystones		2011	20	94					4	96					4
						2018	27	97					3	98					2

*according to Viewegh et al. (2003), Tree species codes: DF – Douglas fir, NS – Norway spruce, SP – Scots pine, BI – silver birch, OK – sessile oak, EL – European larch (see Jenkins et al. 2012).

3. Results

Thinning regimes (Fig. 1) led to lower amounts of annual litterfall in DF-dominated plots Pol1 and Obo compared to unthinned control (Fig. 2). As for the whole-period, total sums of litterfall were also reduced between 2011 – 2018; the thinned treatment values were found to be close to those of control values in mixed DF–SP plot Pol2 (Table 2). The reduction amounted to 1.2 t (5%) whereas both DF–dominated plots showed even less dry mass amounting 3.9 (8%) and 6.0 t (10%) in Pol1 and Obo plots respectively. Mean annual litterfall was 170 kg lower in Pol2, 563 kg in Pol1 and 773 kg in Obo compared to their unthinned treatments. Differences (long-term lower amount of litterfall under thinned stands compared control stands) were 15% (p–value 0.10).

The less dry mass return the lower nutrient return. The only slightly higher N and P return in thinned Pol2 (Fig. 3) was found due to slightly higher, though insignificantly, concentrations of these nutrients. As for the litterfall nutrient concentrations, N oscillated between 0.8 – 1.3% -, Ca 0.4 – 0.8% -, P 0.04 – 0.10%, K 0.09 – 0.16% and Mg 0.04 to 0.06% which accounted for an annual litterfall return amounting 30 – 50 kg of N, 2 – 3 kg of P, 3 – 5 kg of K, 12 – 30 kg of Ca and 1 – 2 kg of Mg per one hectare of young DF–dominated young stands (Table 2).

We also observed, that litterfall turnover under young DF stands was relatively fast (Fig. 4). Although litterfall amounted 20 – 30 t per hectare (Fig. 4) between 2011 and 2018, dry mass of forest floor horizons L+F of only two control plots (Pol1 and Obo) was ca 4 t per hectare higher compared to the thinned treatments. Effect of thinning was observed on the upper forest floor layers as all thinned plots showed increased decomposition rates reflected in lower total L+F amounts in both DF-dominated plots and also in reduced L and increased F layer in the mixed DF–SP Pol2 plot (Fig. 4).

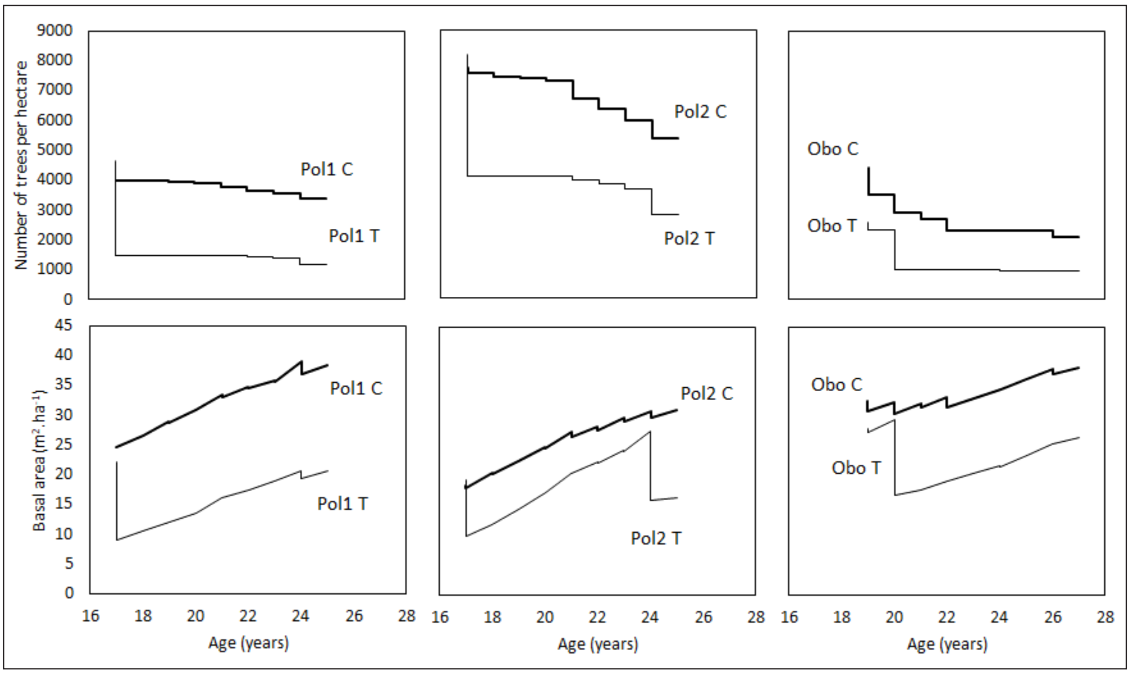

Fig. 1. Number of trees (above) and basal area (below) on experimental plots with litterfall observation (for plot designation see Table 1).

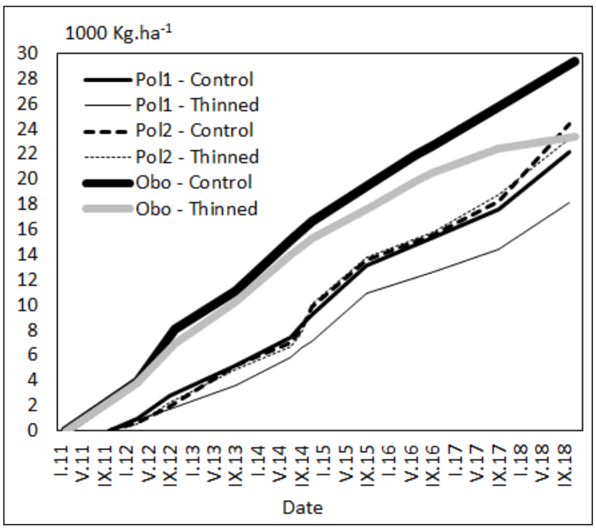

Fig. 2. Cumulative amount of litterfall dry mass in the period between 2011 – 2018 (for plot designation see Table 1).

Table 2. Amount of dry-mass and nutrients in litterfall under young Douglas-fir stands (for plot designation see Table 1).

	Plot	Dry mass	Nutrients				
			N	P	K	Ca	Mg
Amount for observation period 2011 – 2018 [kg ha⁻¹]	Pol1 C	22 121	293.0	20.4	30.5	103.0	14.0
	Pol1 T	18 177	220.3	13.7	25.3	84.4	11.8
	Pol2 C	24 419	188.0	10.6	29.9	112.2	12.4
	Pol2 T	23 227	209.5	11.9	22.4	86.3	9.5
	Obo C	29 373	394.0	26.9	41.8	240.7	16.3
	Obo T	23 383	312.4	21.2	30.5	165.8	12.1
Amount for mean annual litterfall [kg ha⁻¹]	Pol1 C	3 160	41.9	2.9	4.4	14.7	2.0
	Pol1 T	2 597	31.5	2.0	3.6	12.1	1.7
	Pol2 C	3 488	26.9	1.5	4.3	16.0	1.8
	Pol2 T	3 318	29.9	1.7	3.2	12.3	1.4
	Obo C	3 790	50.8	3.5	5.4	31.1	2.1
	Obo T	3 017	40.3	2.7	3.9	21.4	1.6

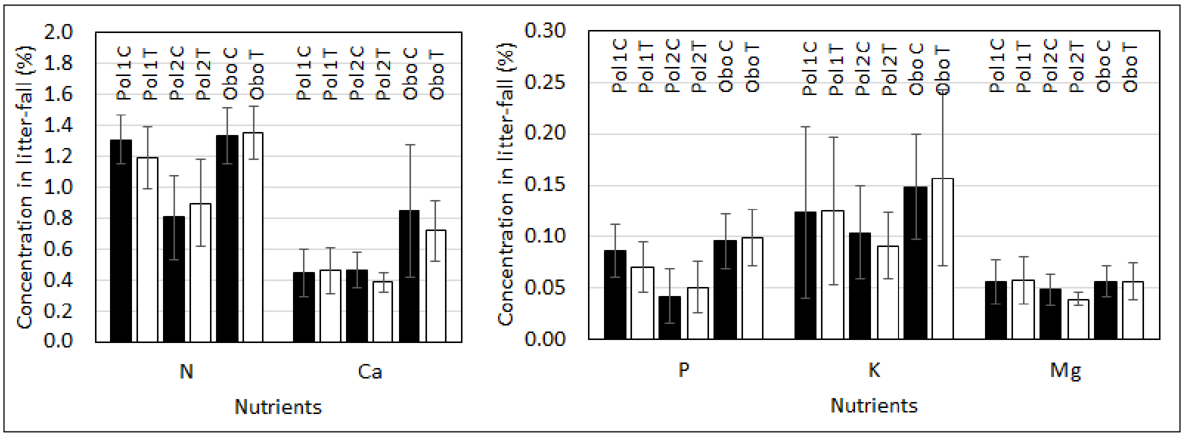

Fig. 3. Concentrations (mean with S.D.) of nutrients (left – N and Ca, right – P, K and Mg) in litterfall under young Douglas-fir stands (for plot designation see Table 1).

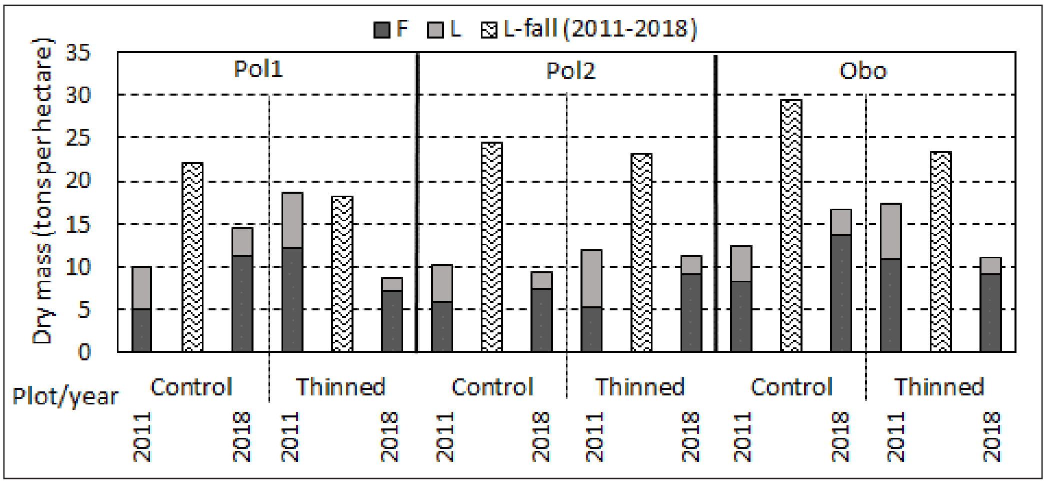

Fig. 4. Change of dry-mass accumulation in horizons L and F under differently thinned young Douglas-fir stands in connection with litterfall dry mass for the same period (for plot designation see Table 1).

4. Discussion

As for the DF litterfall amount, 20-year-old stands were reported as shedding between 1.4 and 2.5 t ha^{-1} of dry mass annually (Turner & Long 1975; Binkley et al. 1984). In 40-year-old and older stands, annual dry mass litterfall ranged between 1.4 – 3.5 t ha^{-1} (Will 1959; Mcshane et al. 1983; Fried et al. 1990; Longdoz et al. 2000; Berg et al. 2001). This, however, does not mean that litterfall increase mainly with the age. On the other hand the litterfall seems to be strongly related to basal area (Novák et al. 2014) which increases with the age; G is also strongly related to the total stand biomass of DF (Ponette et al. 2001). Besides G, also other stand production characteristics such as wood volume, above-ground biomass and mean annual increment correlated strongly with mean annual litterfall (Erkan et al. 2018). Maguire (1994) reported more released necromass through branch mortality from larger DF trees and denser plots with DF. In our 17 – 25-year-old experiments, the annual litterfall amounted to ca. 3 t ha^{-1} which was attributable to differences in stand density and G. For example Turner & Long (1975) reported 1.4 t ha^{-1} litter that fell off annually from the 23-year-old, thinner (650 trees ha^{-1}) stand with G amounting 9.7 m^2 ha^{-1} whereas 22-year-old, much denser (2 756 trees ha^{-1}) stand with higher G (42 m^2 ha^{-1}) showed 2.5 t ha^{-1} of litterfall (Binkley et al. 1984).

Although differences among tree species litterfall have been described (e.g. Augusto et al. 2002). Observed amounts of DF litterfall are consistent with those ones shown in the Czech native commercial conifers (Kacálek et al. 2018). It is also in accordance with Hansen et al. (2009), who reported no significant differences among litterfall amounts of tree species such as Norway spruce, Sitka spruce, Douglas fir, European beech and common oak in common garden experiment in Denmark. Hansen et al. (2009) concluded that previously reported large variability in forest floor accumulation should primarily be attributed to differences in litter decomposition.

The monitoring time span is a crucial prerequisite for getting reliable data as year-on-year amounts of falling-off litter vary which is confirmed e.g. by Will (1959) or Trofymow et al. (1991). The fluctuating values are also attributable to climate oscillations. As for the annual nutrient return, our values amounting ca. 30 – 50 kg N, 1 – 3 kg P, 3 – 5 kg K, 12 – 30 kg Ca a 1 – 2 kg Mg are similar to ranges reported for DF stands by other authors (Will 1959; Turner 1981; Fried et al. 1990; Trofymow et al. 1991).The litterfall amount itself is not, however, the most important from forest nutrition point of view. Density reduction of stands with higher basal area would result in more water available for trees and also in higher nutrient release (or lower nutrient immobilization) from decomposing needle litter (Bueis et al. 2018) which is a positive effect to the site though the total amounts of litter are reduced.

Thinning reduces litterfall amount (del Río et al. 2017) as the stand density is controlled deliberately. This can be expected if the pre-thinned stands are homogeneous. Accordingly, we observed higher differences (lower litter-fall due to thinning) in DF-dominated plots (Pol1 and Obo) compared to plot Pol2 with higher initial density, higher share of other species (Scots pine) and lower thinning intensity (by G). The trees left on site use more light, additional water and more available nitrogen (Chase et al. 2016) to increase the diameter increment and enlarge crowns thus closing the canopy again which increases litterfall gradually (Roig et al. 2005; Erkan et al. 2018). Trofymow et al. (1991) reported 15-year reduction of DF litterfall after removal of 2/3 of G at the age of 25 years. DF old-growth stands are expected to reduce foliage due to humidity stress and severe air temperature which also reduces transpiration rate and increase soil moisture (Dong et al. 2018). Therefore, the role of thinning, which emulates natural loss of needles, is to help stands cope with the climatic extremes.

Our results did not confirm the fear of the excessive accumulation of raw litter in forest floor under DF-dominated stands. The upper two horizons (L+F) accumulated 9 – 19 t ha^{-1} of dry mass. Similar (3 – 15 t ha^{-1}, Šarman 1982) and even higher (25 – 26 t ha^{-1}, Podrázský et al. 2006) results were reported for Norway spruce, or European beech where it amounted 14 – 18 t ha^{-1} (Podrázský & Viewegh 2005). Relatively quick decomposition observed in our experiment was additionally accelerated by thinning (confirmed on two experimental plots with lower initial density, lower share of other species and higher thinning intensity). It was in accordance with results of Wright (1957) and Wilhelmi (1988) for Norway spruce or Blanco et al. (2008) for Scots pine. In those studies, there were reported greater both litterfall and forest floor accumulation in unthinned or in (only) light-thinned stands. How this effect is reflected in the stocks of nutrients in the forest floor und upper soil horizons, it needs further and more detailed research and we included it into following analyses in our experiments.

5. Conclusion

Young DF-dominated stands react to very heavy thinning by lower amount of litterfall and quicker rate of litter decomposition. This effect showed similar trend compared to native conifers (Norway spruce, Scots pine). Thus DF can be recommended as the commercial species in the Czech Republic conditions which do not pose any excessive risk if used as admixed species with native broadleaves or conifers.

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