Norway spruce litterfall and forest floor in the IUFRO thinning experiment CZ 13 - Vítkov

J. Novák, M. Slodičák, D. Dušek, D. Kacálek

Forestry and Game Management Research Institute, Jíloviště-Strnady (Prague), Opočno Research Station, Opočno, Czech Republic

ABSTRACT: The effect of thinning on litterfall and decomposition of biomass was investigated in Norway spruce IUFRO thinning experiment (CZ-13), Czech Republic. The experiment was established in 1971 in an 8-year-old spruce stand on former farmland. Quantity and quality of litterfall and biomass from humus horizons were analysed in two treatments (1C – no thinning, 2T – heavy thinning at the young age). Forest floor was investigated in 2002, 2004, 2005 and 2009 and litterfall was observed in the period 2002–2009. Accumulated dry mass in forest floor after 39 years of existence of spruce stands continually decreased until the age of 46 years (from 80–100 to 30–50 Mg·ha^{-1}). Under thinned stand, a lower amount of dry mass was observed compared to the control. Although mean total annual litterfall was the same in both treatments (5.3 Mg·ha^{-1}), the observed trend indicates a possible effect of thinning on the higher rate of decomposition. With the exception of calcium (2002–2005 samples) we found the forest floor lower in nutrients and litterfall higher in nutrients in thinned plot compared to the control. Our results supported the theory that early thinning is an appropriate silvicultural strategy helping spruce to cope with growth conditions on sites naturally dominated by broadleaves.

Keywords: forest-floor layers; litterfall; Norway spruce; thinning

Plant-tissue litterfall is a significant pathway to return nutrients and carbon to the soil in forest ecosystems (Hansen et al. 2009). The organic remnants of plants accumulated on the soil surface are collectively referred to as forest floor (Briggs 2004); it accumulates because of the slow decomposition process (Singer, Munns 1996). As this forest floor decomposes, it creates particular organic horizons of litter (L), fermented material (F) and humus (H). The presence of these surface organic layers distinguishes forest soils from agricultural ones (Torreano 2004). There were great changes in land use in the past; forests that had been converted into agricultural land became forest land once again due to both succession and afforestation. In the Czech Republic, the area of afforested land expanded especially after World War II. Norway spruce is the tree species dominating in new forests though spruce is not a native species on many sites.

The spruce-oriented forestry (across a spectrum of sites) has both advantages and disadvantages such as well-developed management; excellent production; wide range of wood usability, low stability or supposed soil degradation. However, in the short term, the increased nutrient immobilization in trees does not create an apparent depletion of available base cations (Bélanger et al. 2004).

At present, we observed declining spruce stands especially on sites at lower altitudes where spruce suffers from a coincidence of low precipitation and high air temperature, i.e. on the sites where a spruce share in the species composition should be limited. Extensive coniferous forests are presently found in many European countries and have changed the natural species composition to the detriment of broadleaf forests (Spiecker et al. 2004).

On the other hand, we would even find vigorous spruce stands on sites naturally dominated by

Supported by the Ministry of Agriculture of the Czech Republic, Project No. MZE 0002070203.

broadleaves in the Czech Republic. Spruce stands are extremely productive there and forest owners prefer the spruce management to the restoration of native forests.

Not only altered climatic conditions such as higher temperature and lower precipitation are expected during climate change. Among the other changes, a higher nitrogen deposition can start nutrient imbalance in spruce stands. Berg et al. (2001) and Berg and Meentemeyer (2002) supposed that N-rich litter should have a larger resistant fraction left than N-poor litter resulting in a significantly higher accumulation of humus under Norway spruce stands. Similarly, Kleja et al. (2008) found that higher N deposition and N availability under spruce along a climatic gradient in Sweden resulted in the slower turnover of soil organic matter in the south than in the north. Michel and Matzner (2002) also supported a hypothesis that long-term high N deposition would lead to increased accumulation of C in forest floor.

A task of Norway spruce nutrient turnover is rather complicated and cannot be solved only by conversion of the tree species composition. Thinning seems to be one of the appropriate methods to influence nutrient storage and fluxes in forest stands. Many studies have been carried out on the effect of thinning and other management practices on decomposition and nutrient cycling in forests, but the results differ from site to site (Berg, McClaugherty 2003).

The objective of our study was to reveal how both quantity and quality of litterfall and forest floor could be influenced by thinning of young spruce stands being threatened by climatic variations. The experimental plot belongs to such a type of sites mentioned above. Our study addresses the following research question: Is it possible to influence litterfall and forest floor accumulation by thinning?

MATERIAL AND METHODS

Site and stand

Thinning experiment CZ-13, Vítkov was established in 1971 in an 8-year-old spruce thicket having an initial density of 2,500 trees·ha^{-1}. The experimental plot is a secondary coniferous forest growing on former agricultural land (Slodicak et al. 2005). After afforestation, the locality was not either limed or fertilized. The stand is situated on a south-eastern slope (0–5%) at an altitude of 600 m. The coordinates are 49.838685 and 17.586778. Soil is classified as pseudogleyic (aquic) Cambisol. The potential natural vegetation would be a moist to wet forest (*Abieto-Fagetum fraxinosum humidum – Athyrium filix-femina),* according to Viewegh et al. (2003) composed of beech (*Fagus sylvatica* L.) mixed with silver fir (*Abies alba* Mill.). According to data from the Vítkov meteorological station (15 km apart, south-west of the experiment), mean annual precipitation totalled 698 mm and mean annual temperature was 7.4°C in the period 1961–2010. As for the growing season (April–September), mean annual precipitation totalled 448 mm and mean annual temperature 13.7°C for the period 1961–2010 (Fig. 1).

Experimental design

The Vítkov experiment is a part of European-wide series, established under the auspices of IUFRO in 1971 (Abetz 1977; Slodicak et al. 2005). Only two variants (1C and 2T) as a part of the standard IUFRO experimental design were used for the investigation of litterfall and forest-floor characteristics. Treatment 2T is a heavy thinning regime at young age (low thinning at the top height of 10, 12.5

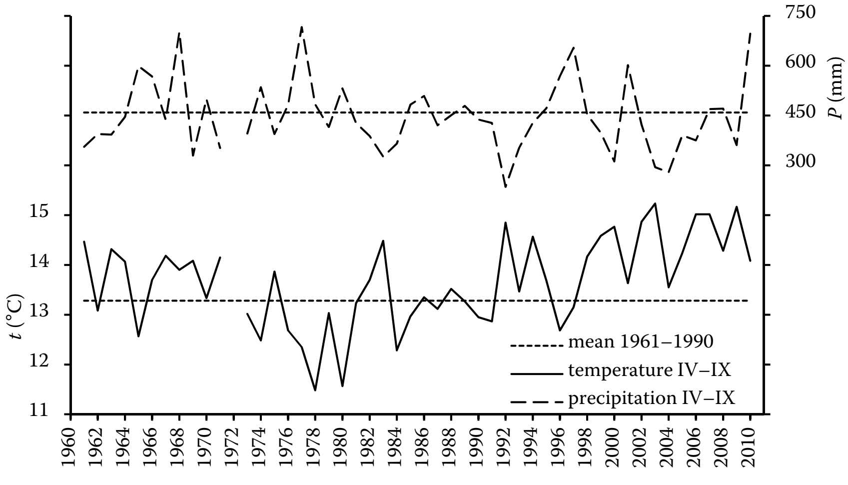

Fig. 1. Mean amount of precipitation and mean air temperature in the growing season 1961 – 2010 (April to September), source of data: Vítkov meteorological station (Czech Hydrometeorological Institute)

J. FOR. SCI., *59*, 2013 (3): 107–116

and 15 m removing 53, 25 and 23% of individuals) mostly by negative selection from below. This thinning regime is compared with a variant without thinning (treatment 1C). The size of each original comparative plot is 0.1 ha. Both diameter at breast height and height were measured regularly in the stands at one-year intervals.

Density management

The number of trees on treatment 2T was reduced from the initial density of 2,545 trees to 1,200 trees·ha^{-1} at the top height of 10 m (age of 15 years, 1978). The second and third thinning was done at the top height of 12.5 and 15 m (age of 19 and 22 years, 1982 and 1985) and the number of trees decreased to 905 and 695 trees·ha^{-1}, respectively. The observed mortality in the subsequent period was found to be low in this variant. Final density represented 640 trees·ha^{-1} at the end of the investigation period (2009, age of 46 years). On the other hand, only salvage cut was done in control treatment 1C. Stand density decreased from initial 2,500 to 1,650 trees (i.e. total reduction about 34%) at the end of the investigation period.

During the 36-year investigation (1971–2007), the basal area increased in both variants. IUFRO series started at the age of 8 years and the initial basal area was 2.4 and 2.9 m^2·ha^{-1} in control and thinned plots, respectively. After the first experimental thinning in 1978 (age of 15 years, top height 10 m), the basal area in control and thinned plots was 25.6 and 14.0 m^2·ha^{-1}, respectively. Thirty-one years later, these differences almost disappeared due to salvage cuts in the control. For treatments 1C and 2T these respective values were 68.8 and 56.4 m^2·ha^{-1} at the age of 46 years (2009).

Consequently, an important factor in evaluating the litterfall and surface humus layer formation is different basal area of comparative treatments (1C – control and 2T – thinned) during 31 years.

Forest floor and litterfall sampling

Litterfall was collected using 10 litter collectors (each 0.25 m^2 in area) installed within stands (1C, 2T) in October 2002. The samples were taken twice to fourth times per year until November 2009. Results from the first year of litterfall observation (2002–2003) were partly published (Slodicak et al. 2005).

In autumn 2002, when the stands were 39 years old, forest-floor humus horizons (L = fresh litter, F = fermented layer and H = humus) and mineral topsoil (A horizon) were investigated quantitatively and qualitatively in comparative plots (1C – control and 2T – thinned). Additionally, sampling was repeated in autumn 2004, 2005 and 2009. The samples were taken using steel frames (25 × 25 cm) to demarcate an area for collecting all enclosed material (three samples in 2002 and 2005, and four and six samples in 2004 and 2009, respectively) in both plots.

All samples were dried, first in the open air, later in a laboratory oven at 80°C, and dry samples were subsequently weighed. Values of weight are presented in Mg·ha^{-1}, it means thousand kilograms per ha.

Nutrient content was assessed in composite samples from each comparative plot (after mineralization with 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.

Additionally, in horizon A we measured the concentration of oxidizable carbon (C_{ox}) from composite samples using spectrophotometric determination of organic carbon in soil via oxidation with chromosulphuric mixture and colorimetric analysis (Walinga et al. 1992). Nitrogen content was determined in composite samples (three per treatment) after mineralization with mineral acids and analysed using the Kjeldahl procedure. Base saturation in horizon A was analysed by Kappen method (Valla et al. 1983).

Data were analysed using descriptive statistics (i.e. inferential statistics was avoided) because treatments were not replicated.

RESULTS

Dry mass of litterfall

Because of different time of sampling in the particular years (intervals between samplings were irregular) we calculated mean annual litterfall from the samples which were taken from October 2002 to November 2009, i.e. during the entire seven-year period.

The total dry weight of annual litterfall under observed stands reached 5.3 Mg·ha^{-1} in both observed

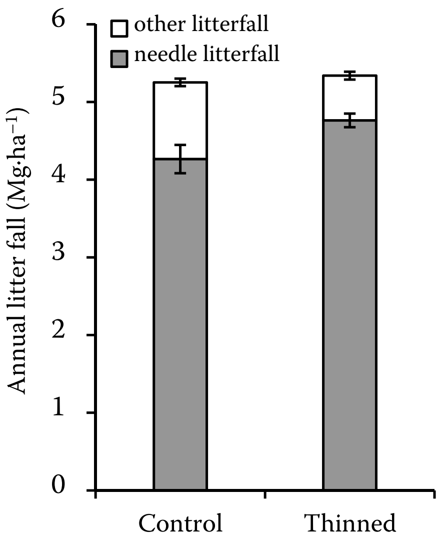

Fig. 2. Annual litterfall (dry mass) in unthinned control plot (1C) and heavily thinned plot (2T) in the IUFRO CZ-13 thinning experiment near Vítkov in the period 2002–2009 (age of 39–46 years). Presented values are arithmetical means with standard errors for the above-mentioned period divided by the number of years

plots (mean values from seven years of monitoring, Fig. 2). We found significant differences in litter composition between treatments with a higher share of needles in thinned plot 2T (89%, 4.8 Mg·ha^{-1}) compared to control plot 1C (81%, 4.3 Mg·ha^{-1}).

On the other hand, a portion of the other litterfall components (small twigs, buds, etc. excluding cones) was significantly higher in control plot 1C (0.99 Mg·ha^{-1}) compared to thinned plot 2T (0.58 Mg·ha^{-1}).

Dry mass in forest floor

The results showed that the 39-year-old Norway spruce monoculture on former agricultural land accumulated 98.2 and 82.9 Mg·ha^{-1} of biomass in humus horizons L, F and H in treatments 1C and 2T, respectively (Fig. 3). Two, three and seven years later we found always a lower amount of biomass in these horizons (66.6 and 62.2 Mg·ha^{-1} in 2004, 67.2 and 55.8 Mg·ha^{-1} in 2005 and 47.8 and 27.3 Mg·ha^{-1} in 2009 in treatments 1C and 2T, respectively). We found always lower values (about 16%, 7%, 17% and 43% in 2002, 2004, 2005 and 2009, respectively) in thinned plot 2T compared to control plot 1C.

Consequently, we observed similar trends for individual horizons, i.e. dry mass of horizons was always higher in the control plot compared to the thinned one. In the first year of observation (2002) we found the highest amount of dry mass in horizons L + F, 36.6 and 25.9 Mg·ha^{-1} on plot 1C and 2T, respectively (difference between plots being 29%). In the next years, the amount of dry mass in these horizons decreased (22.0 and 21.0 Mg·ha^{-1} in 2004 and 25.8 and 19.2 Mg·ha^{-1} in 2005 on plots 1C and 2T) and differences between treatments were smaller (5% and 25%). The largest difference between plots (37%) was found in 2009 (18.5 and 11.6 Mg·ha^{-1} in plot 1C and 2T, respectively) when the amount of dry mass in horizons L + F was the lowest in the period of observation.

Dry mass of humus (H) continually decreased during period of observation (61.6, 44.6, 41.4 and 29.3 Mg·ha^{-1} in plot 1C and 57.0, 41.2, 36.6 and 15.7 Mg·ha^{-1} in plot 2T in 2002, 2004, 2005 and

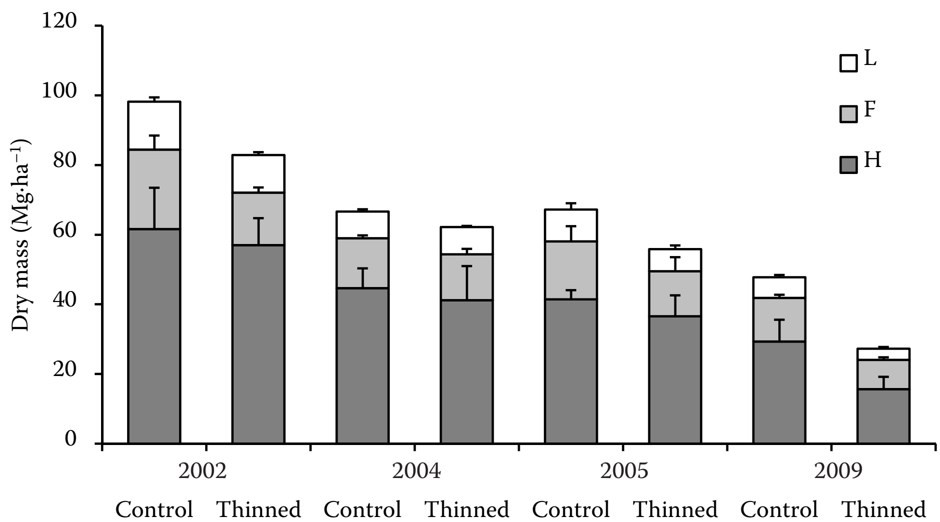

Fig. 3. Decreasing amount of dry mass in forest floor (horizons L + F + H) for unthinned control plot (1C) and heavily thinned plot (2T) in the IUFRO CZ-13 thinning experiment near Vítkov in 2002, 2004, 2005 and 2009 (age of 39, 41, 42 and 46 years). Presented values are arithmetical means with standard errors

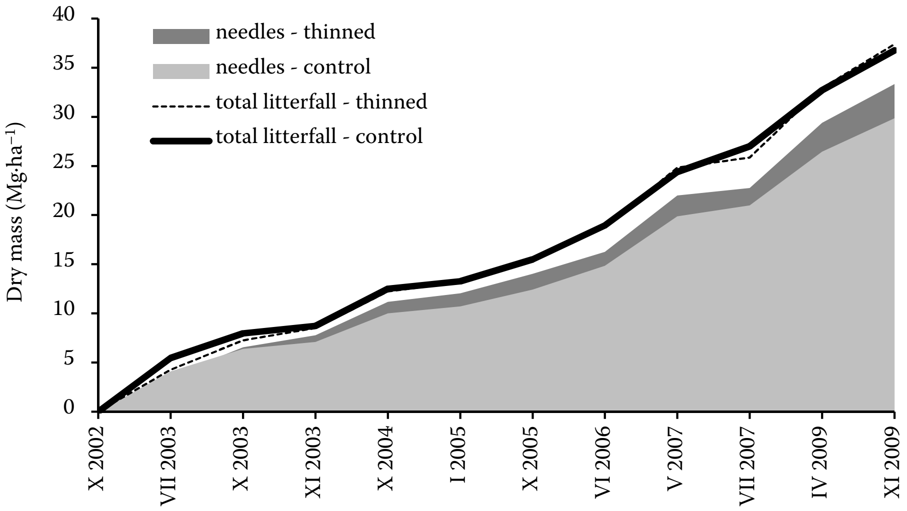

Fig. 4. Dry mass of litterfall in unthinned control plot (1C) and heavily thinned plot (2T) in the IUFRO CZ-13 thinning experiment near Vítkov in the period 2002–2009 (age of 39–46 years). Presented values are arithmetical means in cumulative depiction

2009, respectively). Differences between treatments (a higher amount in the control plot) increased in the particular years: 7, 8, 12 and 47% in 2002, 2004, 2005 and 2009, respectively.

Dry mass – comparison between litterfall and forest floor

During the period of observation (2002–2009) dry mass of litterfall reached comparable values 36.8 and 37.4 $Mg \cdot ha^{-1}$ in plot 1C and 2T (Fig. 4). On the other hand, the amount of dry mass in horizons L + F + H fell by 51% (50.4 $Mg \cdot ha^{-1}$) and 67% (55.6 $Mg \cdot ha^{-1}$) in 1C and 2T treatments during the same period (from 98.2 and 82.9 $Mg \cdot ha^{-1}$ in 2002 to 47.8 and 27.3 $Mg \cdot ha^{-1}$ in 2009). It means that approximately 87 $Mg \cdot ha^{-1}$ of dry mass was decomposed in control treatment over the seven years of observation. Thinning increased the decomposition by 6 $Mg \cdot ha^{-1}$ resulting in 93 $Mg \cdot ha^{-1}$.

Nutrients in litterfall

Mean annual litterfall consists of approx. 50 kg of N, 3 kg of P, 7 kg of K, 75 kg of Ca and 3 kg of $Mg \cdot ha^{-1}$ in control unthinned treatment and the amount of nutrients in litterfall was higher in thinned treatment (Table 1). As for N, P and K, differences between the treatments were small (1%, 3% and 4%, respectively). On the other hand, litterfall under the thinned stand was by 25% and 32% higher in Ca and Mg compared to the control plot.

Nutrients in forest floor

Nutrient amount in forest floor (L + F + H) showed a similar trend like the dry mass analyses, i.e. lower values were found in the thinned treatment compared to the control one (Table 2). The forest floor in thinned treatment 2T was by 20, 11,

Table 1. Amount of nutrients in litterfall in unthinned control plot (1C) and heavily thinned plot (2T) in the IUFRO CZ-13 thinning experiment near Vítkov in the period of 2002–2009 (age of 39–46 years). Presented values are arithmetical means with standard errors for the above-mentioned period divided by the number of years

Treatment	Statistics	N	P	K	Ca	Mg
		(kg·ha⁻¹)				
1C	mean	49.60	3.10	7.30	75.30	2.50
	SE	2.06	0.14	0.44	3.41	0.14
2T	mean	49.90	3.20	7.60	93.80	3.30
	SE	0.94	0.07	0.21	1.81	0.07

SE – standard error

22 and 40% lower in nitrogen compared to control 1C in 2002, 2004, 2005 and 2009, respectively. The total nitrogen pool ranged between 625 and 920 kg·ha^{-1} in control plot and between 374 and 735 kg·ha^{-1} in thinned plot 2T.

The pools of phosphorus continually decreased in both variants in 2002–2009 (from 165 to 26 kg·ha^{-1} for control and from 82 to 12 kg·ha^{-1} for thinning). Thus, the amount of phosphorus was lower in the thinned plot by 50, 4, 47 and 54% in 2002, 2004 and 2005, respectively.

In thinned plot, we found the lower amount of potassium by 23, 15, 21 and 40% (in 2002, 2004 and 2005, respectively) compared to control plot. Being similar to the above-mentioned nutrients, the amount of potassium continually decreased during the observation period in both treatments (from 729 to 289 kg·ha^{-1} in control plot and from 559 to 173 kg·ha^{-1} in thinned plot).

As regards calcium, the results seemed to be different, i.e. the continually falling amount was not found over the years of observation. In control plot, the amount of calcium ranged between 114 and 219 kg·ha^{-1} in the period 2002–2005. At the same time, the amount of calcium increased in thinned plot from 167 kg·ha^{-1} (in 2002) to 226 kg·ha^{-1} (in 2005). At the end of the observation period (2009), the pool of calcium was lower compared to previous sampling in 2005 in both variants observed (157 kg·ha^{-1} in control plot and 102 kg·ha^{-1} in thinned plot).

A different trend compared to other nutrients was also found when comparing both treatments. Thinning increased the calcium amount by 4, 88 and 3% in 2002, 2004 and 2005, respectively and reduced by 35% in 2009 compared to the control.

Magnesium amount followed the trends of other nutrients (N, P and K), i.e. a continual loss during the observation period in both treatments (from 128 to 40 kg·ha^{-1} on control plot and from 95 to 24 kg·ha^{-1} on thinned plot). Thinned treatment was always lower in magnesium (by 26, 36, 14 and 40% in 2002, 2004, 2005 and 2009, respectively).

Nutrients – comparison between litterfall and forest floor

In spite of the continual refill of forest-floor nutrients due to annual litterfall, the total amount of nutrients was lower in 2009 compared to the ini-

Table 2. Amount of nutrients in forest floor (horizons L + F + H) in unthinned control plot (1C) and heavily thinned plot (2T) in the IUFRO CZ-13 thinning experiment near Vítkov in 2002, 2004, 2005 and 2009 (age of 39, 41, 42 and 46 years)

Year	Treatment	Statistics	N	P	K	Ca	Mg
			(kg·ha^{-1})				
2002	1C	mean	917	165	729	160	128
		SE	12.8	58.6	185.6	2.2	24.9
	2T	mean	735	82	559	167	95
		SE	158.3	13.9	73.3	68.1	17.3
2004	1C	mean	804	69	589	114	89
		SE	106.8	10.7	88.2	10.6	11.5
	2T	mean	715	66	501	214	57
		SE	64.2	13.9	163.9	65.6	9.1
2005	1C	mean	923	58	416	219	50
		SE	85.2	11.5	132.7	14.9	8.7
	2T	mean	717	31	328	226	43
		SE	168.4	4.5	53.8	81.6	8.5
2009	1C	mean	625	26	289	157	40
		SE	64.1	3.5	50.1	12.4	6.1
	2T	mean	374	12	173	102	24
		SE	52.4	2.3	34.5	8.8	2.1

SE – standard error

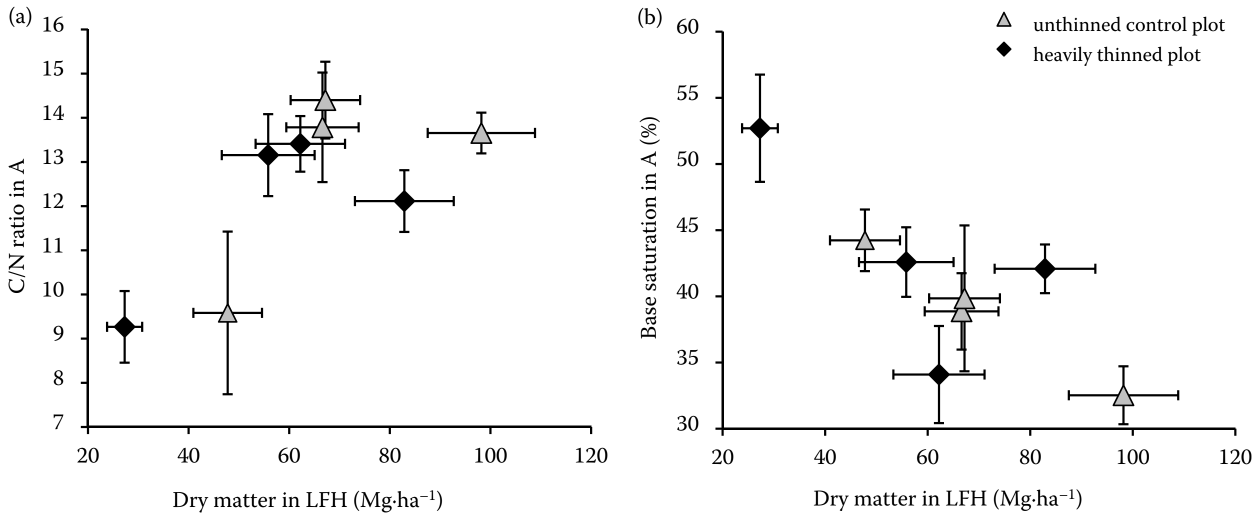

Fig. 5. Relation between dry matter in forest floor (L + F + H) and C/N ratio (a) and base saturation (b) in horizon A for unthinned control plot (grey triangle) and heavily thinned plot (black diamond) in the IUFRO thinning experiment at Vítkov in the period 2002–2009 (age of 39–46 years)

tial results in 2002. Differences between nutrient amounts in forest floor (L + F + H) in 2002 and 2009 plus the 7-year sum of litterfall (i.e. 321 kg of N, 21 kg of P, 64 kg of K, 575 kg of Ca and 21 kg of Mg in control plot and 347 kg of N, 22 kg of P, 67 kg of K, 622 kg of Ca and 26 kg of Mg in thinned plot) showed that the forest floor lost high nutrient amounts in both variants. The thinning even increased the loss of forest-floor nutrients compared to control plot; we found by 43% less phosphorus (160 and 92 kg·ha^{-1} in 1C and 2T), by 10% less potassium (504 and 455 kg·ha^{-1} in 1C and 2T) and by 11% less magnesium (109 and 97 kg·ha^{-1} in 1C and 2T). The loss of nitrogen (by 16%) and calcium (by 19%) from forest floor was also higher in thinned plot compared to control plot (613 and 708 kg of N and 578 and 687 kg of Ca per ha in 1C and 2T).

The relatively high decomposition rate of forest floor (and also litterfall in fact) was reflected in topsoil properties (C/N ratio and base saturation) in both treatments. During the period of observation C/N ratio showed the values from 9 to 14 and a higher amount of dry mass in forest floor (L + F + H) was accompanied by higher C/N ratio (Fig. 5a).

Base saturation in horizon A ranged from 33 to 53%; the lowest values of base saturation in horizon A accompanied the highest amount of dry mass in forest floor (Fig. 5b).

DISCUSSION AND CONCLUSIONS

The forest stands situated on former agricultural soils are suitable for studies of forest-floor humus accumulation since the organic layers of litterfall origin are a result of the first-generation forest stand restoration. In other words, there is no legacy of a previous forest stand. Ouimet et al. (2007) reported the beginning of forest floor accumulation at the age of ten years. Time seems to be an important factor of forest environment development. This is obvious in our study as we recorded the continually decreasing amount of dry mass in forest floor compared to previously published data from this experiment (Slodicak et al. 2005). At the end of the observation period (2009) the forest floor amounted to 30 to 50 Mg·ha^{-1}. This value is in accordance with results from the 40-years-old spruce stands observed by Podrázský et al. (2009). They reported 39 Mg·ha^{-1} of dry mass per hectare in forest floor on former agricultural land on a poorer site at a lower altitude.

Ritter et al. (2003) reported a continuously increasing amount of accumulated forest floor of spruce origin. However, our results seem to show a little different situation as the amount of biomass covering the soil decreased between 2002 and 2009. The forest floor in the thinned variant of our study tended to have a lower amount. It is in accordance with Wright (1957), who reported that the greater litterfall and forest-floor accumulation can be found in moderately thinned or unthinned Norway spruce stands. Nilsen and Strand (2008) found no significant difference in carbon storage related to thinning in a 33-year-old stand. However, Norway spruce stands were able to sequester a significantly higher amount of carbon in developing forest floor compared to oak as reported by Vesterdal et al. (2002).

The relatively high amount of litterfall (nearly 9,000 kg·ha^{-1}) documented at the beginning (Slodičák et al. 2005) was not confirmed during the following years of our study. The observed values of mean annual litterfall (5.3 Mg·ha^{-1}) correspond better to 1.1–5.7 Mg·ha^{-1} reported by Bille-Hansen and Hansen (2001); Berg and Meentemeyer (2001); Novák and Slodičák (2004) in spruce stands at similar age. Hansen et al. (2009) reported lower average annual litterfall ranging between 3.2 and 3.7 Mg·ha^{-1}·yr^{-1}. Very high litterfall observed in our experiment in 2003 was probably caused by severe drought observed across Europe in that year (Nikolova et al. 2008).

The annual litterfall did not differ between the two treatments in our study in contrast to published results (Wilhelmi 1988; Novák, Slodičák 2004). However, we found differences in litter composition. Needles in thinned variant accounted for 89% in litterfall whereas needles in unthinned (control) plot accounted for 81% only. For instance, Skovsgaard et al. (2006) found out that the foliage biomass of spruce increased with increasing thinning grade being related to factors such as tree size changing due to larger spacing.

Faster decomposition of forest floor and different litter composition (higher portion of other litterfall) between variants can be explained by different stand development in the period of observation (2002 to 2009). We recorded salvage cut on control plot (12% of the number of trees, 9% of basal area) whilst the number of trees in thinned treatment remained practically unchanged (4%) and basal area increased continually in that period (salvage cut was only 4% of G). As regards total litterfall, small differences between variants can be attributed to the long period since the last thinning in plot 2T (1985).

There is another factor which is likely to contribute to increased decomposition – rising air temperature in the vegetation period (April–September). The mean air temperature of vegetation period was higher in all years of observation (2002–2009) compared to the mean values in 1961–1990 (Fig. 1).

The pools of nutrients followed the amounts of forest floor dry mass, i.e. lower values in thinned plot. However, we observed the higher amount of calcium and magnesium in litterfall in thinned plot compared to control plot. On the other hand, Jonard et al. (2006) found also a negative effect of thinning on nutrient concentrations (N, P, K) in current-year needles whereas Ca and Mg concentrations were not affected.

Calcium in forest floor showed a different trend compared to the other nutrients investigated. The forest floor was higher in Ca under thinned stand. Although the difference was relatively small, it occurred three times in 2001, 2004 and 2005. It can be explained by a slower release of Ca from litter compared to K and Mg as reported by Blair (1988). He discussed that the main reason for this is the nature of Ca as a structural component of plant litter. Therefore, the release of Ca is more dependent on biotic activity than on leaching.

As for C/N ratio, it is considered a reliable indicator as to the degree of humus decomposition and soil organic matter quality (Batjes 1996). The forest floor humus of young, initial-stage accumulation has high C/N values since the organic layer covering the soil is composed mainly of raw plant matter (Briggs 2004) high in carbon. As this plant matter decomposes, the C/N value decreases and conditions improve as to nitrogen supply (Singer, Munns 1996). During decomposition, CO_2 is released as decomposers breathe and the remaining nitrogen decreases the C/N ratio of forest floor (Šimek 2003). However, the breakdown of plant matter turns also the other nutrients into a plant-available status. Thus the higher rate of forest floor decomposition being reflected in the lower C/N ratio of mineral topsoil (A horizon) resulted in mineral topsoil higher in base nutrients (Fig. 5).

It can be concluded from the study of Norway spruce monoculture established on former agricultural land on a site naturally dominated by broadleaves:

– the amount of dry mass accumulated over 39 years of existence of spruce stands in forest floor (horizons L + F + H) continually decreased in the subsequent observation period to the age of 46 years (from 80–100 Mg·ha^{-1} to 30–50 Mg·ha^{-1}),
– under thinned stand (heavy thinning at young stage), a lower amount of dry mass was observed in the entire period of investigation compared to unthinned control. Although mean total annual litterfall was the same in both treatments (5.3 Mg·ha^{-1}), the observed trend indicates a possible effect of thinning on the higher rate of decomposition,
– with the exception of calcium (in forest floor in 2002–2005) we observed a lower amount of nutrients in forest floor and a higher amount in litterfall in thinned plot compared to the control,
– the relatively high decomposition rate of forest floor (and also litterfall in fact) was reflected in decreasing C/N ratio and increasing base saturation in topsoil (horizon A) during the period of observation.

Thus, successful survival of Norway spruce established on sites naturally dominated by broadleaves (i.e. out of optimal growing conditions for spruce) can be supported by early thinning (before reaching the top height of 10 m). Presented silvicultural measures increased the decomposition rate and positively changed the nutrient cycling. However, these results should be confirmed by subsequent (and repeated) research in all sites where spruce grows under non-optimal conditions where a massive decline of these stands occurred or is expected.

References

Abetz P. (1977): Programme of the European research in stem number of spruce (*Picea abies* Karst.). Mitteilungen der Forstlicher Versuchs- und Forschungsanstalt Baden-Württemberg, ***80***: 15–21.

Batjes N.H. (1996): Total carbon and nitrogen in the soils of the world. European Journal of Soil Science ***47***: 151–163.

Bélanger N., Paré D., Bouchard M., Daoust G. (2004): Is the use of trees with superior growth a threat to soil nutrient availability? A case study with Norway spruce. Canadian Journal of Forest Research, ***34***: 560–572.

Berg B., McClaugherty C., de Santo A.V., Johnson D. (2001): Humus buildup in boreal forests: effects of litter fall and its N concentration. Canadian Journal of Forest Research, ***31***: 988–998.

Berg B., Meentemeyer V. (2001): Litter fall in some European coniferous forests as dependent on climate: a synthesis. Canadian Journal of Forest Research, ***31***: 292–301.

Berg B., Meentemeyer V. (2002): Litter quality in a north European transect versus carbon storage potential. Plant and Soil, ***242***: 83–92.

Berg B., McClaugherty C. (2003): Plant Litter: Decomposition, Humus Formation, Carbon Sequestration. Berlin, Springer-Verlag: 338.

Bille-Hansen J., Hansen K. (2001): Relation between defoliation and litterfall in some Danish *Picea abies* and *Fagus sylvatica* stands. Scandinavian Journal of Forest Research, ***16***: 127–137.

Blair J.M. (1988): Nutrient release from decomposing foliar litter of three tree species with special reference to calcium, magnesium and potassium dynamics. Plant and Soil, ***110***: 49–55.

Briggs R. D. (2004): The forest floor. In: Burley J., Evans J., Youngquist J.A. (eds): Encyclopedia of Forest Sciences. Oxford, Elsevier: 1223–1227.

Hansen K., Vesterdal L., Schmidt I.K., Gundersen P., Sevel L., Bastrup-Birk A., Pedersen L.B., Bille-Hansen J. (2009): Litterfall and nutrient return in five tree species in a common garden experiment. Forest Ecology and Management, ***257***: 2133–2144.

Jonard M., Misson L., Ponette Q. (2006): Long-term thinning effects on the forest floor and the foliar nutrient status of Norway spruce stands in the Belgian Ardennes. Canadian Journal of Forest Research, ***36***: 2684–2695.

Kleja D.B., Svensson M., Majdi H., Jansson P.E., Langvall O., Bergkvist B., Johansson M.B., Weslien P., Truusb L., Lindroth A., Ågren G.I. (2008): Pools and fluxes of carbon in three Norway spruce ecosystems along a climatic gradient in Sweden. Biogeochemistry, ***89***: 7–25.

Michel K., Matzner E. (2002): Nitrogen content of forest floor Oa layers affects carbon pathways and nitrogen mineralization. Soil Biology & Biochemistry, ***34***: 1807–1813.

Nikolova P. S., Raspe S., Andersen C. P., Mainiero R., Blaschke H., Matyssek R., Haberle K. (2009): Effects of the extreme drought in 2003 on soil respiration in a mixed forest. European Journal of Forest Research, ***128***: 87–98.

Nilsen P., Strand L. T. (2008): Thinning intensity effects on carbon and nitrogen stores and fluxes in a Norway spruce (*Picea abies* (L.) Karst.) stand after 33 years. Forest Ecology and Management, ***256***: 201–208.

Novák J., Slodičák M. (2004): Structure and accumulation of litterfall under Norway spruce stands in connection with thinning. Journal of Forest Science, ***50***: 101–108.

Ouimet R., Tremblay S., Périé C., Prégent G. (2007): Ecosystem carbon accumulation following fallow farmland afforestation with red pine in southern Quebec. Canadian Journal of Forest Research, ***37***: 1118–1133.

Podrázský V., Remeš J., Hart V., Moser W. K. (2009): Production and humus form development in forest stands established on agricultural lands – Kostelec nad Černými lesy region. Journal of Forest Science, ***55***: 299–305.

Ritter E., Vesterdal L., Gundersen P. (2003). Changes in soil properties after afforestation of former intensively managed soils with oak and Norway spruce. Plant and Soil, ***249***: 319–330.

Singer J.S., Munns D.N. (1996): Soils, an Introduction. New Jersey, Prentice Hall: 480

Skovsgaard J.P., Stupak I., Vesterdal L. (2006): Distribution of biomass and carbon in even-aged stands of Norway spruce (*Picea abies* (L.) Karst.): a case study on spacing and thinning effects in northern Denmark. Scandinavian Journal of Forest Research, ***21***: 470–488.

Slodicak M., Novak J., Skovsgaard J.P. (2005): Wood production, litter fall and humus accumulation in a Czech thinning experiment in Norway spruce (*Picea abies* (L.) Karst.). Forest Ecology and Management, ***209***: 157–166.

Spiecker H., Hansen J., Klimo E., Skovsgaard J.P., Sterba H., von Teuffel K. (eds) (2004): Norway spruce Conversion – Options and Consequences. EFI Research Report 18. Leiden-Boston-Köln, Brill: 320

Šimek M. (2003): Základy nauky o půdě: Neživé složky půdy. [Fundamentals of Soil Science: Inanimate Components of Soil.] České Budějovice. Jihočeská univerzita: 131.

Torreano S. (2004): Soil development and properties. In: Burley J., Evans J., Youngquist J. A. (eds): Encyclopedia of Forest Sciences. Oxford, Elsevier: 1208–1216.

Valla M., Kozák J., Drbal J. (1983): Cvičení z půdoznalství II. [Practice of Soil Science II.] Praha, Státní pedagogické nakladatelství: 281.

Vesterdal L., Ritter E., Gundersen P., Karjalainen T. (2002): Change in soil organic carbon following afforestation of former arable land. Forest Ecology and Management, ***169***: 137–147.

Viewegh J., Kusbach A., Mikeska M. (2003): Czech forest ecosystem classification. Journal of Forest Science, ***49***: 85–93.

Walinga M., Kithome M., Novozámský I., Houba V.G. J., Van Der Lee J.J. (1992): Spectrophotometric determination of organic carbon in soil. Communications in Soil Science and Plant Analysis, ***23***: 1935–1944.

Wilhelmi V. (1988): Düngung und Durchforstung als kombinierte Waldsanierungsmaßnahme. Allgemeine Forstzeitschrift, ***159***: 844–846.

Wright T.W. (1957): Some effects of thinning on the soil of a Norway Spruce plantation. Forestry, ***30***: 123–133.

Received for publication November 8, 2012
Accepted after corrections February 20, 2013

Corresponding author:
Ing. Jiří Novák, Ph.D., Forestry and Game Management Research Institute, Opočno Research Station, Na Olivě 550, 517 73 Opočno, Czech Republic
e-mail: novak@vulhmop.cz