Chapter 4

Litter Fall and Forest Floor under Conifer Stands: Silviculture Consequences - A Review

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Additional information is available at the end of the chapter

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Abstract

Litter fall is an important part of nutrient cycle in forest ecosystems. Conifers are traditionally considered to be less-suitable nutrient cycling improvers and/or maintainers compared to broadleaves. Long-term observations plus information from both domestic and international publications showed an important role of conifers in process of accumulation and decomposition of the forest floor. Our results also show relations between litter fall and forest floor amounts due to thinning. From silviculture point of view, the knowledge of nutrient cycling is essential to optimize tree species composition using appropriate techniques for forest regeneration and thinning.

Keywords: Norway spruce, *Picea abies*, Scots pine, *Pinus sylvestris*, European larch, *Larix decidua*, thinning

1. Introduction

Soil fertility is being maintained and/or improved via litter fall partly. To evaluate impact of tree species on forest soils, knowledge of forest floor development and its properties is essential. The properties of forest floor layers are attributable to tree species composition and soil properties that are developed under conditions of different climates. The forest floor consists of three particular layers (see [1, 2]). Forest floor humus amount is typically a result of many years' litter fall [3].

These layers were described [2]: L-litter at the surface consisting of shed foliage and other plant matter that is mostly undecomposed which means that particular organs can be recognized

(**Figure 1** and **Figure 2** on the left); F-layer of partly decomposed plant remnants, recognizable organs and parts still prevail, the matter of unrecognizable origin is already present including soil biota remnants, presence of fungi is obvious (**Figure 2** in the middle); H-humus consisting of mostly heavily decomposed matter excepting partly recognizable remnants of roots (**Figure 2** on the right). Mineral topsoil below H layer is called an organic-mineral soil; it contains 20–30% of humus and are 5–30 cm deep [2]. Waterlogging contributes to development of deeper (even 50 cm) peaty horizon [2].

The main measure to avoid development of overstocked, dense and thus less-stable stands is thinning. Thinning reduces standing aboveground biomass as the residues are left on site and/or removed from the stand and used commercially. Both approaches affect production of litter fall; the former one, however, increases the annual litter fall in the year of thinning. Thinned stands' forest floors have better conditions to be decomposed more quickly. On the other hand, the trees left on the site have more space and sources to grow that affects growth rate, amount of biomass which increases litter production again.

Sampling of litter fall was conducted using litter collectors in stands of various age on sites both of long-term forested and former agriculture origins. The very beginning of the litter collectors' installation is the stage of the young canopy closure when the oldest needles fall, ground vegetation declines and new forest floor starts to accumulate on the soil surface (**Figures 3** and **4**). Forest floor sampling was done using steel frames (25 × 25 cm in size) to separate the three enclosed L, F and H layers. The review was based on published studies dealing with both litter fall and forest floor produced and developed by three conifers: Norway spruce, Scots pine and European larch. If available, more information from

Figure 1. Sampling of forest floor L layer using steel frames (25 × 25 cm) in Norway spruce stands.

Figure 2. Sampling of forest floor under Scots pine stands—horizons L—litter (left), F—fermentation (in the middle) and H—humus (right).

Figure 3. Litter fall collectors in young Scots pine stands.

Figure 4. Litter fall collectors under control (above) and thinned (below) Norway spruce stands.

unpublished results being relevant to the topic was added. The objective of the study was to gather information on relationship between the three important conifers and the development of forest floor. Authors pointed out, that contrary to popular believes, coniferous litter fall itself should not be considered a single factor contributing to acidity of forest floor.

2. Norway spruce [*Picea abies* (L.) Karst]

Norway spruce does not always develop the worst forest floor conditions [4] though worsening of soil properties was also found (see [5]) which is frequently the reason for converting the species composition or restoration of mixed-species stands [6]. Norway spruce showed its capability of developing similar forest floor properties compared to other tree species [7]. Also unexpected trends were found as Mareschal et al. [8] found higher pH of topsoil (0–5 cm) under 34-year-old Norway spruce compared to stands of Douglas-fir, Corsican pine, European beech and 150-year-old beech-oak coppice while base saturation was the lowest under conifers. Annual liter fall differs according to tree species. Augusto et al. [9] reported litter falls of Scots pine > sessile and English oaks = Norway spruce > Douglas-fir > European beech > European hornbeam > birch amounting 3.9, 3.7–3.8, 3.8, 3.4, 3.5, 2.9 and 2.2 $Mg.ha^{-1}.year^{-1}$ in descending order respectively. Hobbie et al. [10] found an interesting relationship between increased accumulation of coniferous forest floor (silver fir, Norway spruce, Scots and Corsican pines) and content of calcium that seemed to favor earthworms' abundance in calcium-richer small-leaved linden and both sycamore and Norway maple forest floors. Authors of [11] reported higher C/N and accumulated forest floor under Norway spruce compared to English oak.

Development of forest floor relatively higher in nutrients is crucial on nutrient-poor sites [12]. For example, excessively low phosphorus was estimated in large areas in the Jizera Mts., North Bohemia (see [12], p. 83) and Norway spruce forest floors can be higher in phosphorus compared to deciduous broadleaves [13]. More phosphorus was reported from under Norway spruce, European larch and mountain pine compared to silver birch and rowan [13] in the Jizera Mts. Also our unpublished results confirmed more phosphorus under spruce compared to Carpathian birch in the Hrubý Jeseník Mts., North Moravia.

Worse forest floor conditions were frequently attributable to air-pollution load. Kantor [14] found lower forest floor pH under Norway spruce compared to Scots and Corsican pines and broadleaves (European aspen, European beech, silver birch and goat willow) under heavily SO_2-polluted conditions near Trutnov-Poříčí power plant in 1986–1988. More acidic soil and 10 times heavier forest floor was found under Norway spruce compared with linden [15]. Greater accumulation of forest floor is reflected by higher C/N (see [11]). Higher C/N and more phosphorus under Norway spruce were also reported by Dušek et al. [16] compared to small-leaved linden. Also our other unpublished results from Norway spruce and small-leaved linden confirmed the conclusions in [16]. Norway spruce forest floor properties are frequently reported as worse compared to deciduous broadleaves [5, 17–20]. Compared to evergreen conifers, Norway spruce was found to be the same acidifier as Sitka spruce, Scots pine [9], as blue spruce, Serbian spruce [14] and also as silver fir [21] or contributed to worse conditions than white pine [5] or Douglas-fir and silver fir [17].

Thinned Norway spruce stands showed longer living crowns and comparable annual litter fall to nonthinned ones [22]. Nonthinned control plots have greater forest floor amounts than the thinned ones [3, 22]. Norway spruce forest floor accumulates along with the age of stands. 30–40-year-old nonthinned stands showed exceptionally high L + F + H dry-mass values amounting 50–70 $Mg.ha^{-1}$; the values were comparable to other Norway spruce stands of similar age representing particularly 800–1200 kg of nitrogen, 70–90 kg of phosphorus, 80 kg of potassium, 230–370 kg of calcium and 80–160 kg of magnesium [23].

Although the Norway spruce can aggravate acidity of soil, the forest floor and topsoil properties depend not only on the presence of the tree species, but also on synergistic confluence of all biota ecosystem component and environmental conditions of the site. It was Binkley [24] who asked "Why is acidification assumed to be a degradation?" Also Singer, Munns [25] pointed out that acidic soils are typical of conditions "where high rainfall and free drainage favor leaching and the biological production of acids." Norway spruce is a main commercial species on many forest sites from middle altitudes to mountains. Growing Norway spruce becomes risky in conditions of beech with oak and beech sites due to ongoing climate change; Norway spruce, however, remains an important tree species at highland beech with fir, beech with spruce and mountain spruce with beech and spruce sites [26].

3. Scots pine (*Pinus sylvestris* L.)

The topics concerning nutrient cycling are in focus of both researchers and forestry practice due to increasing amounts of logging residues used for energetic purposes (e.g. [27]). Nutrition sustainability is even more important because Scots pine is grown frequently on nutrient-poor, sandy sites and is typical producer of recalcitrant litter. Kantor [14] found Scots pine forest floor less acidic compared to spruces under SO_2-polluted conditions at the end of 1980s. Scots pine was ranked as similarly acidifying tree species compared to Norway spruce and Sitka spruce [9]. Scots pine forest floor properties can be, however, also improved by mixing it with spruce [28, 29], birch [28], beech and oaks [30–32]. Also beech under-planting can improve both amount and diversity of mycorrhiza fungi [33]. Barba et al. [34] reported significant change in forest floor formation as Scots pine is being replaced by Holm oak due to forest die-off. The positive changes in forest floor properties were attributable to soil biota changes; the shift from recalcitrant pine needles input to more palatable oak leaves was important [34]. Keeping pine site fertile is expected from deciduous admixed tree species (see [28, 30–32, 34]).

Young 30-year-old Scots pine stands produce 2–8 $Mg.ha^{-1}$ of litter fall annually. Nitrogen represents ca 0.6% which is a mean input of N totaling 24 $kg.ha^{-1}.year^{-1}$ [35]. The amount of litter fall increases significantly with increasing basal area and also with reduction of suppressed understory trees [35]. Annual litter fall can be decreased after thinning of the young pines over 8 following years [35]. Nitrogen content (%) is not affected, therefore lower amounts of nitrogen ($kg.ha^{-1}$) in the thinned stand representing 75% of nonthinned control stand litter fall is attributable to removal of litter producers, the trees [35]. If salvage cut is done within the no-thinning stand, litter fall amounts can be equal or even lower than that of the thinned treatment [35]. Annual litter fall can be affected also by climate, which is that the mean temperatures correlate with the annual amounts of litter positively while precipitation correlates negatively [35]. There was also a relationship found between the latitude and content of nutrients such as nitrogen and phosphorus [36]. Also litter higher in nitrogen along with increasing annual actual evapotranspiration was documented [37]. Higher fraction of recalcitrant pine litter was found at sites with higher long-term mean annual temperature [38].

Scots pine needle litter fall decreased along with age was reported [39]. Contrary to this, Berg et al. [40] published a logistic litter fall model showing greater amounts of litter fall in old (over 120 years) than in young (ca 20 years old) stands. Mean needle litter fall is ca 3.9 Mg.ha^{-1} annually and forest floor litter layer totals between 13 and 45 Mg.ha^{-1} [9, 39]; the poorer sites the less litter occurs. The pine forest floor accumulates a less favorable thick humus form of moder-mor type that does not enrich topsoil layers with humus very well. Topsoil high in organic matter develops preferentially under the woody species where higher abundance of earthworms occur [41]. Novák et al. [42] reported 70–123 Mg.ha^{-1} of forest floor layers (L + F + H) under 79-year-old pine stands. The most of forest floor amount was found below no-thinning treatments [42]. The decreased litter fall after thinning in pure Scots pine stands on very poor sites can contribute to development of nutrient deficient forest floor [43]. This can be mitigated by planting deciduous soil improvers (see [28, 30–32, 34]. For instance, neighboring broadleaved stand dominated by European beech accompanied with silver birch, European hornbeam and small-leaved linden showed the top layer (L) of forest floor higher in nitrogen, magnesium, potassium and calcium than Scots pine L in Moravian Sahara near Bzenec, South Moravia. Pine needles were higher in phosphorus. Decomposed FH layers under broadleaves were more base-saturated compared to pine ones ranging between 71 and 81% and 43 and 68%, respectively. The same pattern was found for plant-available phosphorus, potassium, calcium and magnesium. On the other hand, both A and B mineral horizons showed a reverse trend for phosphorus (higher under pine) and comparable base cations content under both broadleaves and pine.

4. European larch (*Larix decidua* Mill)

Humification of litter horizon of larch forest floor was comparable with spruce and slower compared to alder, birch and Scots pine under 25-year-old stand [44]. Podrázský et al. [45] found more than 27 Mg.ha^{-1} of forest floor under European larch while neighboring wild cherry and small-leaved linden accumulated 4 Mg.ha^{-1}; the stands were 60-year-old. The forest floor of European larch origin was lower in base cations (particularly potassium and magnesium) and higher in nitrogen and phosphorus [45]. Below-larch topsoil higher in plant-available phosphorus compared to silver birch, red oak and Norway spruce was found also in [4].

Greater accumulation of larch forest floor is also confirmed on former agricultural land. For example, increased carbon along with age of Siberian larch stands compared to downy birch on volcanic soils of abandoned heath land was found [46]. A thicker L horizon under larch was reported compared to spruce in 53-year-old stands at formerly cultivated site of 600 m altitude [47]; both deeper F and H horizons’ differences were not significant. Larch litter layer was higher in potassium while topsoil was lower in phosphorus and 10–20 cm soil lower in magnesium despite the same soil showed higher pH KCl and base saturation. There is a question if the differences were attributable to legacy of former agriculture [47].

Podrázský and Štěpáník [4] found more acidic soil under European larch than silver birch, red oak and Norway spruce on nutrient-poor, former agricultural soil at middle altitude. Later, [48] the same 28–37-year-old stands of silver birch, red oak, European larch and Norway spruce were compared, less favorable conditions under larch were reported again. There were found, for instance, the lowest pH, base saturation and plant-available nutrients contents excepting phosphorus [48].

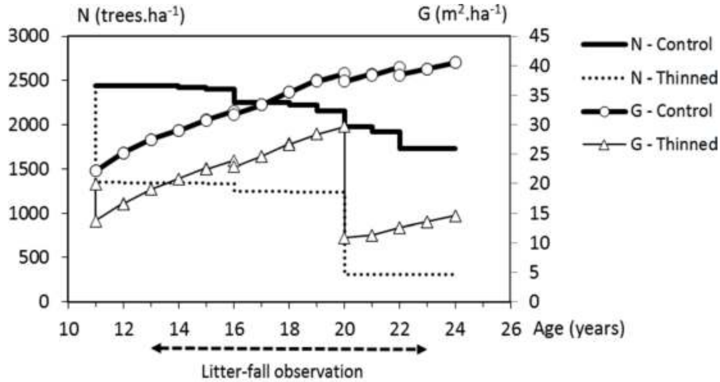
In 50-year-old larch stand on former agricultural land, the LF layer of forest floor was higher in calcium and magnesium, the FH layer was lower in potassium and 0–10 cm topsoil was lower in phosphorus than neighboring Norway spruce stand. Larch topsoil showed also significantly lower C/N [49]. Also another experiment with first-generation European larch forest floor (unpublished results) showed L horizon higher in magnesium and potassium and lower in calcium than spruce. H horizon was higher in all the three base cations under larch. Both H forest floor and topsoil showed the same pH under larch and spruce.

More acidic humus under larch was found also on long-term forested soils in Sweden as lower pH was reported under Siberian larch compared to silver birch and Norway spruce [50]. On the other hand, Eriksson and Rosen [51] reported forest floor of 35-year-old Japanese larch higher in calcium, magnesium, potassium and nitrogen compared to that of grand fir and Norway spruce; no differences were obvious in the mineral soil. We found also more calcium, potassium, magnesium, the same concentrations of phosphorus, nitrogen and slightly less carbon in European larch forest floor than Norway spruce (unpublished results). The forest floor carbon under stands of European beech, Douglas-fir, Scots pine, English oak and Japanese larch was compared in the Netherlands [52]. The values varied between 11.1 $Mg.ha^{-1}$ for beech and 29.6 $Mg.ha^{-1}$ for larch; carbon stocks were lower at managed locations than at unmanaged ones [52].

European larch is also used successfully on post-mining sites [41, 53]. The 29-year development of forests on brown coal mining heap increased significantly dry mass of forest floor under larch compared to broadleaves (oak, linden and alder) and nonsignificantly compared to Scots pine with black pine mixture; the greatest forest floor was accumulated under mixture of Serbian and blue spruce [41]. In the same study, a significant and positive correlation was found between the total soil carbon storage and earthworm density and occurrence of earthworm casts in topsoil [41]. From this point of view, larch was comparable with oak, nonsignificantly higher than other conifers and significantly lower than linden and alder [41]. Similar trends were confirmed by Józefowska et al. [53] on two Polish post-mining sites. Significantly lower biological activity (earthworms, enchytraeidae) and microbial C biomass were found under 30-year-old larch stand compared to broadleaves (oak, birch, alder); biological activity under pine was comparable [53].

Heavy thinning of 20-year-old larch stands reduced significantly litter fall (**Figures 5** and **6**) in the thinned treatment compared to nonthinned control [54]. If used as a substitute tree species in formerly air-polluted Czech mountains, the biomass from thinning for chipping

Figure 5. Litter fall collectors in young European larch stands.



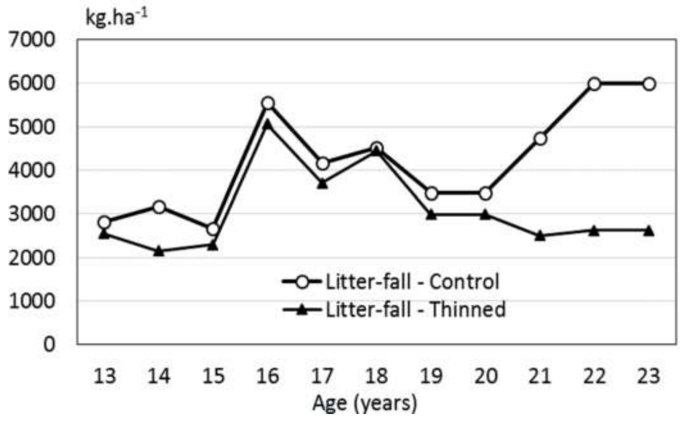


Figure 6. Heavy thinning (above) of 20-year-old European larch stand affected annual litter fall (below); litter fall was slightly higher on control plot after the first thinning at the age of 11 (above); heavy thinning did not decreased litter fall of the thinned treatment substantially, however, that one on control plot increased which made a great difference.

should be limited to stem-wood use only and the remaining aboveground biomass (particularly needles, twigs and branches) should be left on site to be decomposed [55].

5. Silvicultural implications and conclusions

Norway spruce is an important commercial conifer in Central Europe; it grows well on fir-beech to spruce vegetation domains; however, it is also capable of surviving on more sites excepting the flooded ones [56]. Wind, snow, biotic agents and air pollution threaten the Norway spruce stands even in its optimal growing conditions [56].

Scots pine is also important commercial tree species in Central Europe; it is common on natural pine sites, hillside, acidic, gleyic and water-logged sites from lowlands to highlands [56]. Scots pine can be also used as a preparatory pioneer species to restore forest in less-favorable environment such as abandoned sand quarries and so on.

European larch is often used as accompanying tree species on many sites from middle to mountain altitudes [26]. Its forest floor properties are similar to those of evergreen conifers. European larch is not expected to be a soil improver. Larch grows well also outside the original area and is successfully used in mixed stands.

Thinning of young conifer stands can affect annual litter fall over years. Additionally, early thinning increases the decomposition rate and positively impacts on nutrient cycling. The effect is as long as the thinning has been intensive. In case of light or medium thinning, crown biomass increases over a few years and, consequently, amount of litter fall under control and thinned stand becomes comparable again.

Besides the known effects of thinning on quality of production, stability, throughfall and so on, it was confirmed that it is a silviculture measure to influence litter conditions in conifer stands significantly.

However, existing results should be continually verified by following (and replicated) research at all sites where expected climate change is to affect conifers' growth.

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