Quantity and quality of litterfall in young oak stands

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ABSTRACT: Litterfall, an important component of the nutrient cycle in forest ecosystems, was measured for 9 years in young oak stands on two localities classified as beech-oak climax (*Fageto-Quercetum*). We estimated that about 4 Mg of dry mass per hectare fell each year. Nutrient content in the litterfall represents annually per hectare approximately 40–55 kg of nitrogen, 2–3 kg of phosphorus, 7–16 kg of potassium, 41–73 kg of calcium and 6–7 kg of magnesium. The amount of litterfall is positively correlated with stand basal area and with the death of suppressed tress with small crowns. We found a positive correlation between annual litterfall and the sum of precipitation and a negative correlation between annual litterfall and temperature in summer.

Keywords: *Quercus petraea* (Matt.) Liebl.; climatic factors; nutrients

Litterfall is an important component of the nutrient cycle in forest ecosystems. Knowledge of these processes is essential for sustainable forest management. For example, Klotzbücher et al. (2013) found that eight years of doubling litterfall did not change lignin oxidation in mineral topsoils in beech/oak forests. On the other hand, the exclusion of litterfall changed organic matter cycling in A horizons (increased inputs of organic debris, fungi-to-bacteria ratios, and the lignin oxidation). Another result (Tóth et al. 2011) suggests decreases in organic matter content and nutrient concentrations in the soil as a consequence of decline in forest litter production induced by climate change.

Oak (*Quercus robur/petraea)* is the second most represented broadleaved tree species group in forests of the Czech Republic. Although litterfall and forest soils under oak stands have been frequently studied (e.g. Lorencová 2007; Benham et al. 2012), results from young stands are missing.

In the framework of long-term experiments established and managed by Forestry and Game Management Research Institute, Research Station at Opocno, litterfall observations are included for the most prominent tree species (spruce, pine, beech and oak). This paper presents the first results from 9-year observations on two localities naturally dominated by oak. The aim of the study was to find the quantity and quality of litterfall and some factors which influence these characteristics in young (unthinned) oak stands.

MATERIAL AND METHODS

The data were collected during 9-year observations (2003–2011) of litterfall in the young pure oak (*Quercus petraea* [Matt.] Liebl.) stands in different conditions (Table 1). The stands are the unthinned controls of long-term thinning experiments at two locations: Nová Ves (0.06 ha) and Halín (0.08 ha).

Litterfall was measured by collectors of 0.25 m^2 in area randomly placed in each stand (n = 6 for Nová Ves stand, n = 5 for Halín stand). Litter was taken out of collectors twice per year (spring and autumn). Litterfall was collected together for two

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Table 1. Characteristics of observed young oak stands

Plot	Location[1]	Elevation (m)	Soil type	Forest type group[2]	Established by	Start of litterfall observation (2003)				
						Age (yr)	*N* (trees·ha^{-1})	G (m^2·ha^{-1})	d (cm)	h (m)
Nová Ves	49°13'12''N 14°14'56''E	470	cambisol	*Fageto–Quercetum acidophilum*	natural regeneration	20	8,333	20.8	5.3	9.1
Halín	50°19'08''N 16°08'06''E	300	luvisol	*Fageto–Quercetum illimerosum trophicum*	planting	18	10,450	13.1	3.5	5.1

[1]in WGS-84 system, [2]according to Viewegh et al (2003), *N* – number of trees, G – basal area, d – mean diameter at breast height, h – mean height

years, because this site could not be visited regularly. Therefore, we used a simple half value for these years in the framework of analyses.

Samples were not separated into the fractions (leaf, branch, others) because of the young age of the observed stands, which are before the beginning of seed production. Also, natural pruning of branches is limited at that time. All samples from particular collectors were air-dried first and afterwards in the laboratory at 80°C and weighed. Nutrient content was assessed from composite samples from each year after digestion with sulphuric acid and hydrogen peroxide (Turner, Brooks 1992). Total nitrogen (N) concentration was analysed by distilling the Kjehldahl method (Jones et al. 1991) and phosphorus (P) concentration was determined spectrophotometrically (Macháček, Malát 1982). An atomic absorption spectrophotometer was used to determine total potassium (K) concentration by flame emission (Novozamsky et al. 1983), and calcium (Ca) and magnesium (Mg) by atomic absorption (AAS) after addition of Lanthanum (La) (Ramakrishna et al. 1966).

The annual amount of litterfall varied year by year in both stands. Therefore, additional analysis of the relationships between the annual amount of litterfall and stand development (density, basal area) and climatological factors (air temperature at 2 m above the ground, precipitation in the open area and precipitation/temperatures ratio) was performed using Pearson's correlation analysis.

We processed the climatological data from the nearest stations: for the Nová Ves plot, data from stations of the Czech Hydrometeorological Institute (CHMI) were used: Paseky (location 49°14'59''N, 14°16'04''E) for temperatures and Temelín (location 49°11'52''N, 14°20'32''E) for precipitation. For the Halín plot, we used precipitation data from our station located directly near the observed stand and operated by the Forestry and Game Management Research Institute (with the exception of the period 2003–2004, when we used the data from CHMI station České Meziříčí – location 50°16'56''N, 16°02'29''E). Data on temperatures for Halín plot was applied from the CHMI station Hradec Králové (location 50°10'34''N, 15°50'19''E).

RESULTS

Quantity of litterfall

During the nine-year period of observations, mean annual litterfall was 3.7 and 4.1 kg Mg·ha^{-1} of dry mass on the plot Nová Ves and Halín, respectively (Fig. 1). The values of annual litterfall show an increasing trend during the period of observations on both locations. On Nová Ves plot, a minimum

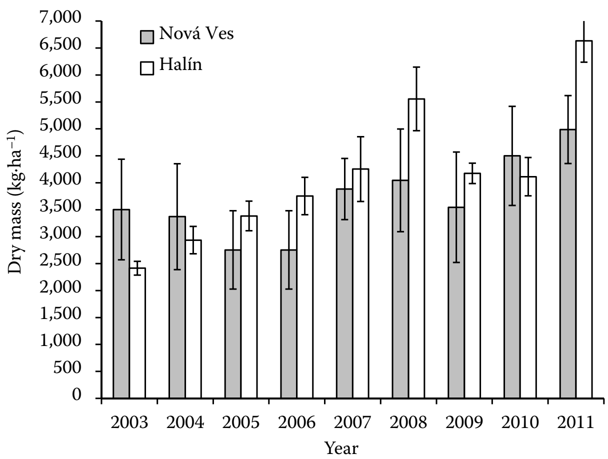

Fig. 1. Mean annual litterfall (means with standard errors) in young oak stands on control plots of experiments Nová Ves (age of 20–28 years) and Halín (age of 18–26 years) in the period of 2003–2011

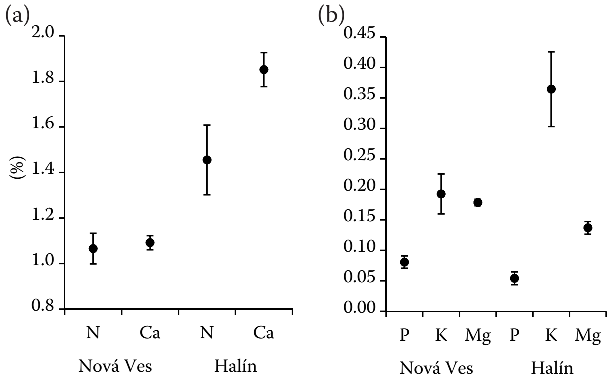

Fig. 2. Amount of nutrients (mean with standard errors) in litterfall in young oak stands on control plots of experiments Nová Ves (age of 20–28 years) and Halín (age of 18 to 26 years) in the period of 2003–2011

amount (2.8 kg Mg·ha^{-1}) was detected in 2005–2006 (mean value for both years – see the methods) and a maximum amount in the last year, i.e. in 2011 (5.0 Mg·ha^{-1}). On Halín plot, the minimum was lower (2.4 Mg·ha^{-1} in 2003) and the maximum was higher (6.6 Mg·ha^{-1} in 2011).

Generally, the inter-annual fluctuation of litterfall was higher on Halín plot. For the first six years, annual litterfall increased at this locality. During the subsequent two years, a lower amount (4.1–4.2 Mg·ha^{-1}) of litterfall was observed. The maximum value of annual litterfall was observed in the final year of measurement. However, on Nová Ves plot, an increasing trend of annual litterfall was observed during the period of observations.

Quality of litterfall

Over the period of observations, mean nutrient content in litterfall biomass was higher in the case of nitrogen (1.4 times), calcium (1.7 times) and potassium (1.9 times) on Halín plot compared to Nová Ves plot (Fig. 2). In contrast, the mean content of phosphorus and magnesium was higher on Nová Ves plot (1.6 and 1.3 times, respectively).

The nutrient content in the litterfall represents on an annual per-hectare basis approximately 40 and 55 kg of nitrogen, 3 and 2 kg of phosphorus, 7 and 16 kg of potassium, 41 and 73 kg of calcium and 7 and 6 kg of magnesium on the plot Nová Ves and Halín, respectively (Table 2). For the observed nutrients, we found large differences between maximum and minimum values (amount of nutrients in kg·ha^{-1}). Most notably, the amount of phosphorus varied dramatically, with maximum values at six times (Nová Ves) and more than fifty times (Halín) higher than minimum values.

Table 2. Calculated amount of nutrients (kg) (mean, maximum and minimum) by annual litterfall in young oak stands on control plots of experiments Nová Ves (age of 20–28 years) and Halín (age of 18–26 years) in the period of 2003–2011

Location		N	P	K	Ca	Mg
Nová ves	mean	39.7	3.0	7.0	40.7	6.6
	max.	65.0	5.5	12.5	64.4	10.2
	min.	31.2	0.9	3.9	34.0	5.5
Halín	mean	55.3	1.7	16.0	73.1	6.1
	max.	134.7	5.4	37.0	129.0	10.6
	min.	25.6	0.1	6.5	36.8	3.7

Litterfall and stand development

On both plots, the number of trees decreased continually (only dead trees were removed) during the study period. At the same time, basal area increased in the young stands (Fig. 3). The basal area is positively correlated with annual litterfall (coefficients for Nová Ves R = 0.66 and Halín R = 0.75). The highest mortality (and consequently the basal area reduction) was observed on Nová Ves plot in 2004, probably due to the severe drought in 2003.

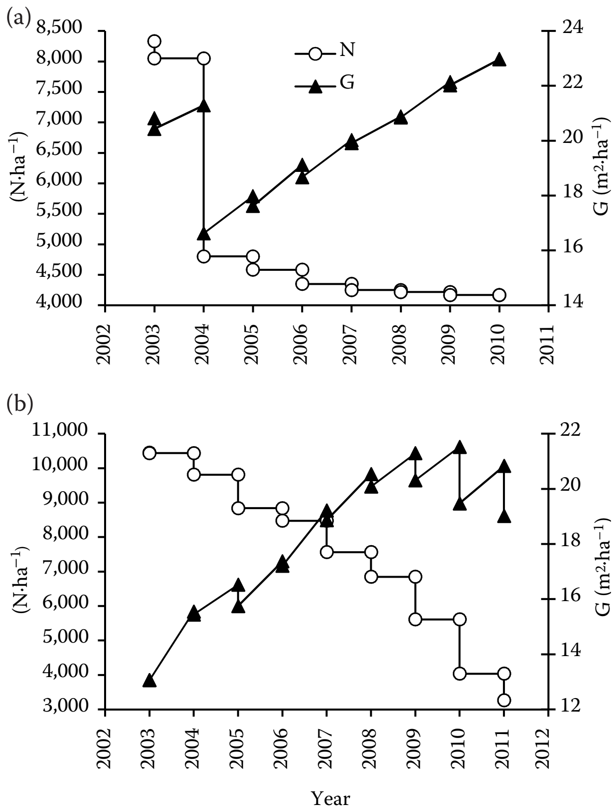

Fig. 3. Number of trees (N) and basal area (G) in young oak stands on control plots of experiments Nová Ves (a) and Halín (b)

On Halín plot, such high mortality was not detected during one vegetation season.

Litterfall and climate characteristics

On the Nová Ves site (Fig. 4), mean air temperature during the growing season was 15.0°C (maximum in 2003 16.8°C, minimum in 2010 14.2°C). The vegetation season at the Halín site was warmer, with a mean temperature of 16.2°C (maximum in 2003 16.9°C, minimum in 2004 15.3°C).

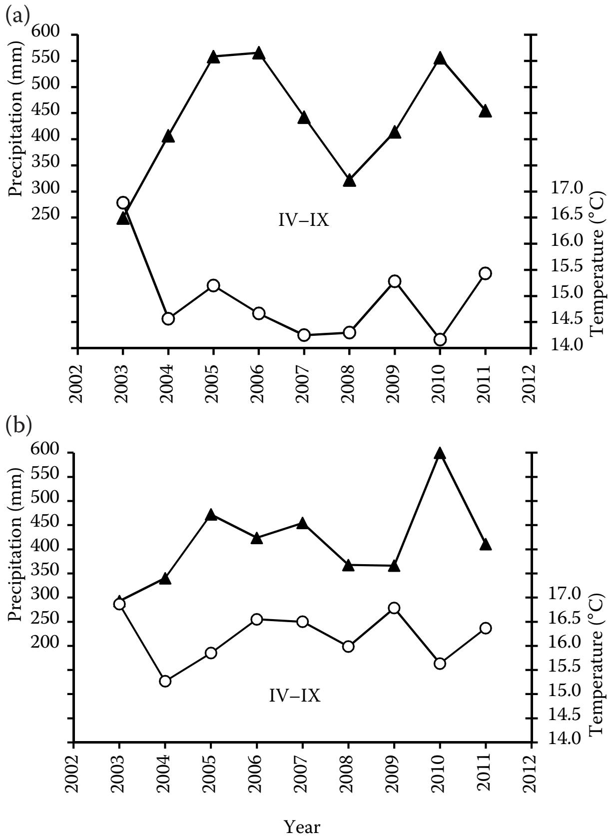

Fig. 4. Mean air temperature (°C) and sum of precipitation (mm) for the vegetation period (April–September) on localities Nová Ves (a) and Halín (b) in the period of 2003–2011

Mean precipitation totals for the vegetation season were 441 and 414 mm in the locality Nová Ves and Halín, respectively. On both plots, the lowest precipitation was observed in 2003 (Nová Ves 249 mm, Halín 293 mm). Maximum values were recorded in 2006 for the area of Nová Ves (566 mm) and in 2010 for the area of Halín (601 mm).

Annual litterfall was positively correlated with the mean temperature and negatively correlated with precipitation and P/T ratio, i.e. the ratio between precipitation and mean temperatures (Fig. 5). At the same time, the observed relationships were weaker in the case of Halín plot. Therefore, we found a positive relationship between annual litterfall and climate characteristics of individual months of the vegetation season.

The amount of annual litterfall was influenced mostly negatively by temperatures in vegetation seasons of individual years on both plots. The highest coefficient was found out for temperature in August (R = –0.42, P = 0.35) on the Nová Ves site. A similar situation was detected on Halín plot but the highest coefficient (R = –0.26, P = 0.50) was calculated for the previous month, i.e. July. On this plot, one (remarkable) case with a positive correlation between the amount of annual litterfall and mean temperatures was detected, namely in April (R = 0.39, P = 0.30).

The relationships between annual litterfall and the sum of precipitation were mostly positively correlated and, compared to the effect of temperatures, higher coefficients of correlation were obtained. The highest coefficient was found out for precipitation in July (R = 0.94, P = 0.001) on Nová Ves plot. A similar situation was detected on Halín plot but the highest coefficient (R = 0.59, P = 0.09) was calculated for the previous month, i.e. June. Other remarkable results in this case were determined for April, August and the entire vegetation period on Nová Ves plot (R = 0.53, 0.44 and 0.54, P = 0.22, 0.32 and 0.21, respectively) and for April and July on Halín plot (R = 0.27 and 0.24, P = 0.48 and 0.53, respectively). On the other hand, the sum of precipitation in May (Halín plot, R = –0.34, P = 0.38) and in June (Nová Ves plot, R = –0.54, P = 0.21) correlated with annual litterfall negatively (Fig. 5).

In the case of precipitation/temperatures (P/T) ratio, similar results like for precipitation were obtained for both plots, partly because (as it was mentioned above) precipitation played a more important role in the relationship to litterfall compared to temperatures.

DISCUSSION AND CONCLUSION

Our results from young *Quercus petraea* stands showing the annual amount of litterfall are comparable to other published studies for stands of deciduous or evergreen oaks. Litterfall per hectare per year for *Quercus robur/petraea* ranged from 2.5 to 11 kg Mg (Carlisle et al. 1966; Christensen 1975; Diaz-Maroto; Vila-Lamerio 2006; Hansen et al. 2009). For other oak species (*Q. potosina, Q. castaneifolia, Q. rotundifolia, Q. coccifera, Q. humboldtii, Q. variabilis, Q. floribunda, Q. lanuginose*) the annual litterfall varied similarly be-

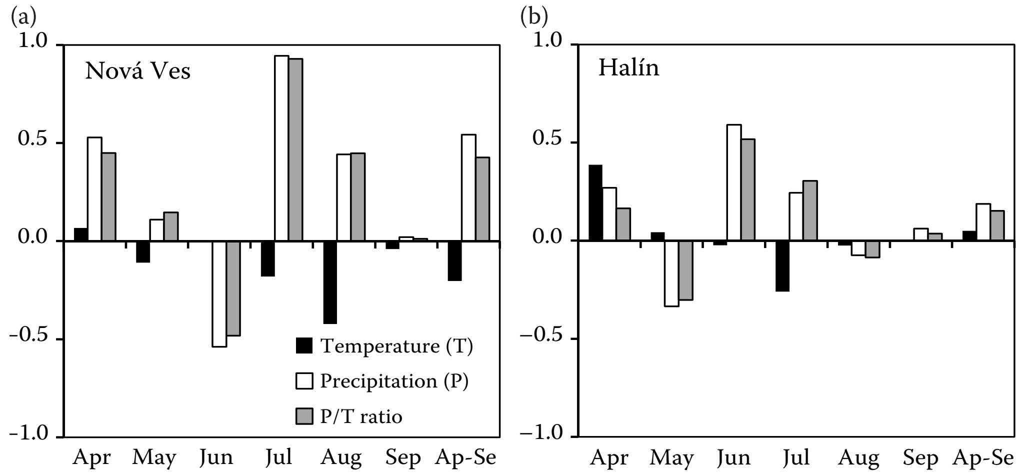

Fig. 5. Coefficients of correlation between annual litterfall and climate characteristics (mean air temperature T, sum of precipitation P and P/T ratio) for individual months and for the vegetation season (from April to September Ap-Se) in experiments Nová Ves (a) and Halín (b)

tween 2 and 8 kg Mg per hectare (Rawat, Singh 1989; Hernandez et al. 1992; Martin et al. 1996; Cañellas, San Miguel 1998; Liu et al. 2001; Santa-Regina 2001; Ramirez-Correa et al. 2007; Rouhi-Moghaddam et al. 2008; Perez-Suarez et al. 2009; Leon et al. 2011). From our observations it is obvious that the inter-annual variability of litterfall amount is relatively high. Therefore, the long-term observation of litterfall is essential for relevant research outputs.

In the case of oak litterfall quality, some studies focused on carbon were published (e.g. Diaz-Pines et al. 2011; Wilson et al. 2012). Based on these referenced studies, one can conclude that litterfall is an important component of C fluxes in oak forests. The amount of nutrients that we found in the litterfall (Table 2) are comparable with the study of Carlisle et al. (1966) from mature stand of *Q. petraea* in the case of N, P and K (annually ca 41.1 kg of N, 2.2 kg of P and 10.5 of K). However, in the basic nutrients Ca and Mg, our results are higher (annually ca 23.8 kg of Ca and 3.9 kg of Mg), likely due to better soil conditions in both of our study sites. On the other hand, two (or more) times higher values for all mentioned nutrients were found in fertile sites for *Q. castaneifolia* (Rouhi-Moghaddam et al. 2008) or *Q. floribunda* and *Q. lanuginosa* (Rawat, Singh 1989). The above-mentioned comparison corresponds with the results of Robert et al. (1986), who found site dependent differences in nutrient content and nutrient remobilization in the litterfall of cork oak (*Q. suber*).

We found a negative correlation between the number of trees and annual litterfall in young oak stands. In contrast, the correlation between the annual amount of litterfall and stand basal area was positive. It is obvious that mainly suppressed trees in the lower canopy strata do not survive on the observed (unthinned) plots because of their shade intolerance. These thin trees usually have small crowns and their contribution to the stand litterfall is minor. On the other hand, the higher basal area of dominant trees means higher litterfall from bigger crowns. This result is in accordance with Hansen et al. (2009), who found a positive ratio between annual litterfall and annual volume increment in oak stand. In our study, the lower values of correlation coefficients in Nová Ves locality were probably caused by two reasons: the above-mentioned large decrease in density in 2004 (Dušek et al. 2011, see Fig. 3) and sampling of litterfall for two years 2005–2006.

The effect of climatic factors on the amount of annual litterfall was not uniform, perhaps due to the relatively short period of observations. On the other hand, the positive correlation between annual litterfall and the sum of precipitation in June (Halín) and July (Nová Ves) and the negative correlation between annual litterfall and temperature in July (Halín) and August (Nová Ves) that we found correspond with results from Vogt et al. (1986), who found that litterfall is affected by climatic factors in deciduous stands more than in stands of conifers. Conditions presented in our study (wet and cooler summer) may contribute to the formation of summer shoots, which increase the amount of annual litterfall.

The significant effect of total precipitation and maximum temperature on the amount of litterfall was confirmed for *Q. robur* stands also in Galicia (Diaz -Maroto, Vila-Lamerio 2006). This effect was more pronounced in the more southerly location (i.e. drier and warmer areas). Martin et al. (1996) found that the inter-annual variability of litterfall amount in *Q. rotundifolia* stand was caused by water stress in summer. Dry spring weather was the reason for the lower amount of litterfall also in *Q. pyrenaica* stand in Spain (Diaz-Pines et al. 2011). Finally, precipitation and water availability as a probable cause of differences in litter production were mentioned by Andivia et al. (2013) in stands of *Q. ilex*.

After 9-year investigations of litterfall under young oak stands we estimated that about 4 Mg of dry mass fell annually per hectare. The amount of litterfall increased with increasing stand basal area and with the death of suppressed trees with small crowns. We found a positive correlation between annual litterfall and the sum of precipitation and a negative correlation between annual litterfall and temperature in summer. These results should be confirmed by subsequent (and replicated) research in other sites where oak is found.

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