JOURNAL OF FOREST SCIENCE, *57*, 2011 (1): 8–15

Aboveground biomass of substitute tree species stand with respect to thinning – European larch (*Larix decidua* Mill.)

J. Novák, M. Slodičák, D. Dušek

Opočno Research Station, Forestry and Game Management Research Institute, Opočno, Czech Republic

ABSTRACT: This study is focused on substitute European larch stands in the Krušné hory Mts. (northern part of the Czech Republic). Research was conducted within larch thinning experiment Kalek (780 m a.s.l. in the category *Piceeto-Fagetum oligo-mesotrophicum – Calamagrostis villosa*). Results showed that the aboveground biomass of the investigated substitute unthinned larch stand represented approximately 102 thousand kg of dry matter per ha at the age of 20 years. Stemwood (ca 59%) is the most important part of the aboveground biomass. Needles, live and dead branches accounted approximately for 6%, 17% and 11%, respectively, and stem bark only for 7%. At the age of 20 years, the investigated substitute unthinned larch stand accumulated: nitrogen – 307 kg, phosphorus – 21 kg, potassium – 136 kg, calcium – 122 kg, magnesium – 53 kg per hectare. Thinning with consequent removal of aboveground biomass may result in nutrient losses. Especially, the removal of whole tree biomass by thinning for chipping in areas previously degraded by acid deposition may result in calcium and magnesium deficiency because of their low content in forest soil. On the other hand, thinning supported faster growth of trees left after thinning and consequently faster biomass and nutrient accumulation. Our results supported the recommendation that the use of biomass from thinning for chipping should be limited to stemwood only and the remaining aboveground biomass (mainly needles and branches) should be left in the forest ecosystem for decomposition in conditions of the historically disturbed area of the Krušné hory Mts.

Keywords: aboveground biomass; European larch; *Larix decidua* Mill.; Krušné hory Mts.; substitute stands; thinning

Forest stands of substitute tree species were established in the Czech Republic at sites where declining spruce monocultures could not be replaced by ecologically suitable tree species due to impacts of continual air pollution and damaged forest soils. The Krušné hory Mts. have been one of the most heavily air-polluted areas since the sixties of the last century (Materna 1999), where the substitute tree species stands take up about 36% of forest land area (Balcar et al. 2008a), i.e. about 41 thousand hectares. Birch (*Betula* sp.) and blue spruce (*Picea pungens* Engelm.) or mixtures of these two species account for the largest percentage of this area. The third species according to coverage is European larch (*Larix decidua* Mill.) with more than 6.5 thousand hectares of forest land in the Krušné hory Mts. (Balcar et al. 2008b).

Larch in the beech with spruce forest vegetation zone (6th forest vegetation zone (FVZ)) is handled as a target tree species and in the spruce with beech 7th FVZ as a transition from target to substitute tree species. As a rule, the larch stands are not envisaged to be subjected to stand conversion and, therefore, proper attention must be paid to their tending.

In connection with the management of substitute stands new questions have arisen: (a) is it possible to remove aboveground biomass from thinning for chipping? and (b) what is the effect of biomass removal on the nutrient balance of stands in these heavily disturbed forest ecosystems? We started answering these questions stepwise. The aboveground biomass of blue spruce stands was determined firstly in the

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

Krušné hory Mts. (Slodičák, Novák 2008) and now research continues in larch stands. The present paper is focused on two problems:

(1) Quantification of aboveground biomass in substitute larch stands in the Krušné hory Mts.
(2) Detection of the amount of main nutrients in the aboveground biomass of substitute larch stands. Both problems are solved with regard to possible nutrient losses after removing a part of aboveground biomass by thinning.

MATERIAL AND METHOD

Research was conducted on Kalek thinning experiment (Novák, Slodičák 2006), established in 1999 to investigate the tending of young larch stands in Litvínov Forest District (Forests of the Czech Republic, state enterprise) in the Krušné hory Mts. The stand is located in the 6th beech with spruce FVZ at an elevation of 780 m a.s.l. in the fresh, medium-nutritive category 6S *Piceeto-Fagetum mesotrophicum* (according to Viewegh et al. 2003). The soil type was classified as Entic Podzol. Mean annual temperature is 6°C; the mean sum of precipitation is ca 800 mm (for the period of 1961–1990). The co-ordinates of the series in WGS- 84 system are 50°35'11"N latitude and 13°21'11"E longitude.

An experimental larch stand was established by line planting (at initial spacing 1 × 1.5 m – 6,667 trees per ha) after mechanical raking of slash to rows. The experimental series consists of four comparative plots 0.04–0.05 ha in size, each divided into partial plots (100 m^2) for statistical evaluation. Two comparative plots were used for presented analyses: (1) – control unthinned plot, (2) – plot thinned at the age of 13 years (in 2000) by negative selection mainly from above (see Novák, Slodičák 2006 for more details). The experimental stands have been measured (diameter at breast height, height, health condition and quality) annually since 1999.

In the period of investigation (2000–2007, age of 13–20 years), the number of trees decreased from 3,400 to 2,280 trees·ha^{-1} (33%) by salvage cutting on control unthinned plot (Fig. 1). On thinned plot, 53% of trees (46% of basal area) were removed by negative selection mainly from above at the age of 13 years. Basal area on control plot increased approximately twice in the period of observation (from 14.3 to 28.6 m^2·ha^{-1} at the age of 13–20 years). On thinned plot, basal area increased after thinning approximately 2.7 times in the period of observation (from 7.8 m^2·ha^{-1} after thinning at the age of 13 years to 21.1 m^2·ha^{-1} at the age of 20 years).

Samples were taken in August 2007 (age of 20 years) using the diameter structure of control larch stand (Fig. 2). Totally 7 sample trees (with diameter at breast height 5, 8, 11, 12, 16, 17 and 24 cm) were chosen for destructive biomass analysis. The sample trees were felled and measured by Huber's method. Besides this common measuring of stem volume (length, diameter by 1 m sections), we collected data on the diameter of branch base (for each branch). For laboratory analyses (dry biomass and nutrient content of needles, bark and wood) sample branches (each tenth from a particu-

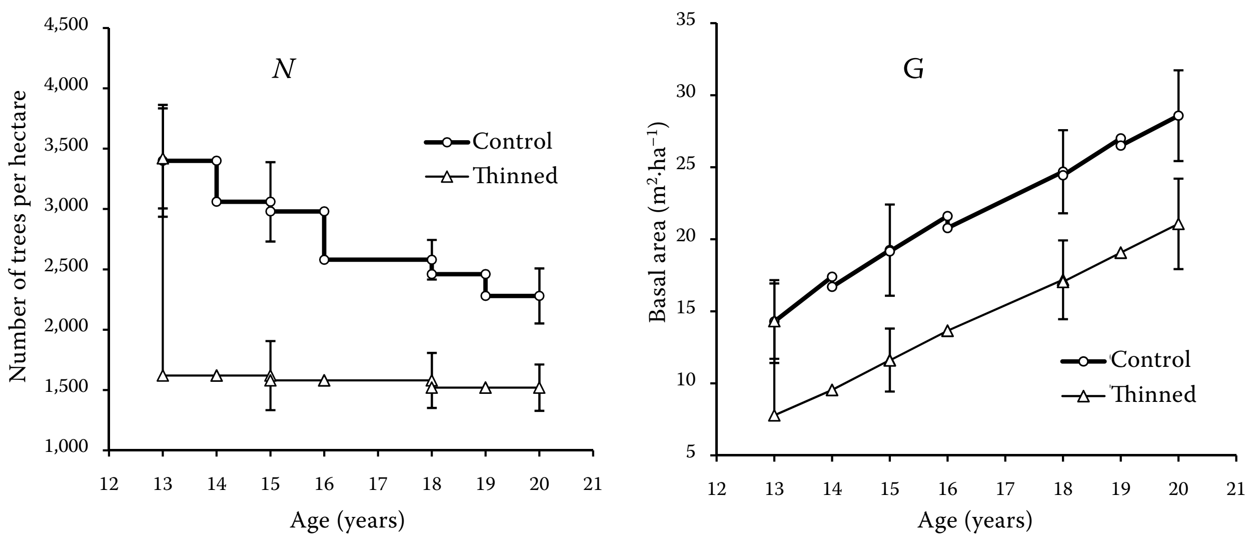

Fig. 1. Number of trees *N* and basal area G (means with standard deviations) of larch stand of experiment Kalek in the Krušné hory Mts. Experimental stand was thinned at the age of 13 years (53% of *N* and 46% of G was removed by negative selection mainly from above – see Methods for more explanation)

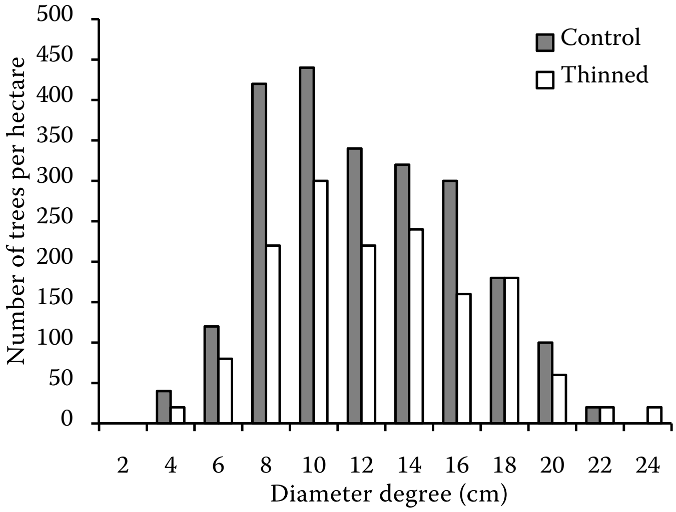

Fig. 2. Diameter structure of observed larch stands at the age of 20 years on two variants (Control and Thinned) of experiment Kalek in the Krušné hory Mts.

lar sample tree) were used. We distinguished live (green) and dry branches. Additionally, we collected for laboratory analyses biomass of all "minor" small branches (dry and green) from each sample tree.

Totally three wood and bark samples (discs approximately 2 cm in thickness) were taken from each sample tree. The first sample was cut off at the distance of 1.3 m from the butt end, the second sample from the middle part of stem and the third from the last quarter of stem.

All samples were dried first in the open air and then in a laboratory at 70°C and weighed. The temperature 65–70°C for drying is used in the majority of studies focused on aboveground biomass. Thus, unless otherwise indicated, this temperature was used throughout the cited works in discussion.

Nutrient content was assessed (after mineralization by mineral acids) from composite samples from each fraction (branches – it means a composite sample of wood and bark of branches, needles, stemwood and stem bark). Total nitrogen (N) concentration was analyzed by the 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 Lanthanum (La).

From the analyses of data from field measurements of sample trees (number and diameter of branches, stem wood volume, stem bark volume) and data from the laboratory (dry biomass, nutrient content) we calculated a model of dependence between diameter at breast height and observed variables. Relationships between diameter at breast height and dry weight of biomass compartments of forest trees were found to be strong in many studies (e.g. Korsuň 1964; Petráš et al. 1985; Černý 1990; Bond-Lamberty et al. 2002; Hochbichler et al. 2006).

Based on the real diameter structure of control stand in 2007 (age of 20 years) we assessed the biomass of particular fractions and total biomass, both including nutrient content. In order to evaluate the effect of biomass removal, we calculated data (by diameter structure) also from the thinned stand at the age of 20 years in the observed stand.

All statistical analyses were performed in statistical software package UNISTAT® (version 5.1). Unless otherwise indicated, test levels of $P < 0.05$ were used.

RESULTS

Calculation and quantification of aboveground biomass

Relationships between diameter at breast height and dry biomass were calculated for the investigat-

Table 1. Coefficients of regression (*a* and *b*) for dry-mass (kg) calculation of larch trees with indexes of determination (R^2)

	a	*b*	R^2
Needles	0.027940	1.800410	0.9837
Dead branches (wood and bark)	0.118280	1.491200	0.8447
Live (green) branches (wood and bark)	0.027960	2.198240	0.9926
Stemwood	0.054380	2.420242	0.9963
Stem bark	0.006588	2.420244	0.9963

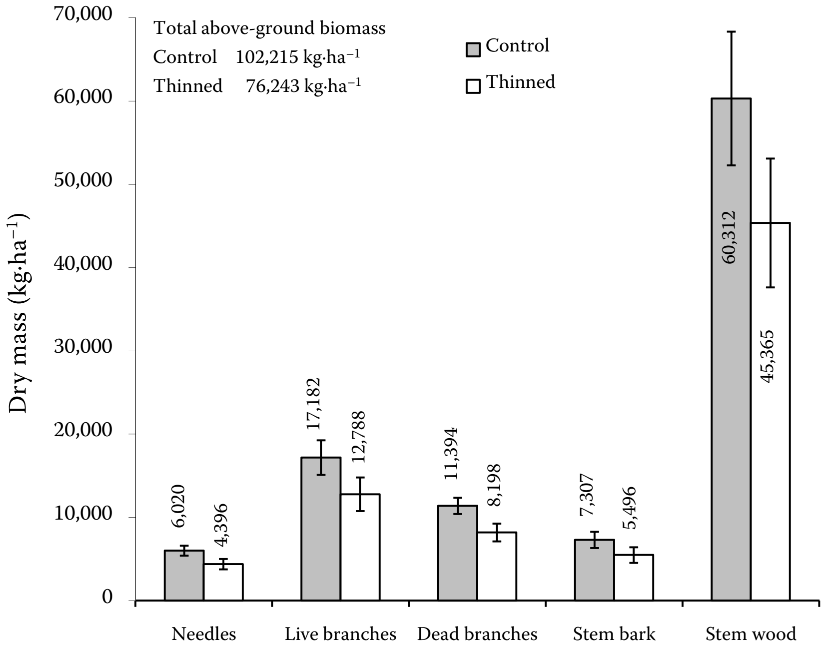

Fig. 3. Amount of above-ground dry mass in kg·ha^{-1} – total and in the individual components (means with standard deviations) of larch stands at the age of 20 years on two variants (Control and Thinned) of experiment Kalek in the Krušné hory Mts

ed parts of larch trees – needles, branches, stemwood and stem bark. Quantification of dry mass of the stand level was done using the constructed allometric equations (for the index of determination see Table 1): $Y = a \times d^b$, where Y is the amount of dry mass, a and b are coefficients (Table 1) and d is diameter at breast height 1.3 m.

At the age of 20 years the total aboveground biomass of the investigated larch stand was 102,215 kg of dry mass per hectare (Fig. 3). The biomass of needles and stem bark was more or less the same – at the age of 20 years it represented approximately 6.0 and 7.3 thousand kg per hectare (i.e. 6% and 7% of total biomass).

Table 2. Amount of nutrients (means with standard deviations) by individual tree components in the above-ground biomass of larch stands at the age of 20 years in the Krušné hory Mts. (experiment Kalek)

Component	Variant		Nutrients in kg·ha^{-1}				
			N	P	K	Ca	Mg
Needles	control	mean	115.0	13.0	35.0	17.0	18.0
		SD	11.5	1.3	3.5	1.7	1.8
	thinned	mean	84.0	10.0	26.0	12.0	13.0
		SD	11.8	1.4	3.6	1.7	1.8
Branches	control	mean	88.0	3.0	35.0	62.0	15.0
		SD	9.5	0.3	4.0	6.4	1.6
	thinned	mean	64.0	2.0	26.0	46.0	11.0
		SD	9.6	0.3	4.0	6.6	1.6
Stem bark	control	mean	34.0	3.0	16.0	13.0	5.0
		SD	4.5	0.4	2.1	1.8	0.7
	thinned	mean	25.0	2.0	12.0	10.0	4.0
		SD	4.4	0.3	2.0	1.7	0.6
Stemwood	control	mean	70.0	2.0	50.0	30.0	15.0
		SD	9.3	0.3	6.6	3.9	3.0
	thinned	mean	52.0	2.0	38.0	22.0	11.0
		SD	9.0	0.3	6.4	3.8	1.9
Total	control		307.0	21.0	136.0	122.0	53.0
	thinned		225.0	16.0	102.0	90.0	39.0

SD – standard deviation

A higher proportion of biomass was found in the fractions of dead and live branches – 11.4 and 17.2 thousand kg·ha^{-1}, and it accounted for 11% and 17% of total biomass, respectively, at the age of 20 years. The most important part of biomass was created by stemwood which represented 60.3 thousand kg·ha^{-1}. It means 59% of total biomass at the age of 20 years.

The total aboveground biomass on thinned plot amounted to 76.2 thousand kg·ha^{-1} seven years after thinning, i.e. 75% compared to control plot (Fig. 3). This amount consisted of 4.4 thousand kg of needles (6%), 12.8 thousand kg of live branches (17%), 8.2 thousand kg of dead branches (11%), 5.5 thousand kg of stem bark (7%) and 45.4 thousand kg of stemwood (59%). The percentage composition of dry mass components was identical both on thinned plot and on control plot.

Amount of main nutrients in aboveground biomass

For the present study nutrient contents in total biomass were calculated (Table 2). Control unthinned stand contained 307 kg of N, 21 kg of P, 136 kg of K, 122 kg of Ca and 53 kg of Mg per hectare in the aboveground biomass at the age of 20 years. In thinned stand, we determined the values of nutrient contents lower by about 25%: totally 225 kg of N, 16 kg of P, 102 kg of K, 90 kg of Ca and 39 kg of Mg were accumulated per hectare at the age of 20 years.

Observed nutrients are located in the tree parts differently (Fig. 4). As regards the nutrient amount in aboveground biomass, the highest portions of some nutrients were stored in needles (37%, 62% and 34% of total aboveground N, P and Mg, respectively). On the other hand, more than one half (51%) of total aboveground calcium was located in branches and more than one third (38%) of aboveground potassium was stored in stemwood. In the observed larch stand, the lowest portions of N, K, Ca and Mg (10–12%) were located in the stem bark. As for aboveground phosphorus, the lowest portion (10%) was stored in stemwood.

DISCUSSION AND CONCLUSION

The aboveground biomass of the investigated substitute larch stand represented approximately 102 thousand kg of dry organic matter per ha at the age of 20 years. In the Czech Republic, only a few studies of young larch stands were published. Results showed lower values of aboveground biomass – 36-years-old stand ca 55.5 t·ha^{-1} with temperature of drying 105°C (Vyskot 1980, 1982). The difference is caused mainly by stand density (about 960 larch trees per hectare in comparison with ca 2,300 larch trees per hectare in our study) and consequently by different characteristics of mean stem.

Foreign results are wider. Total aboveground biomass of larch stands ranges from 80 t·ha^{-1} in 50-60-years-old stand (Young et al. 1980 in Burrows et al. 2003), 158 t·ha^{-1} in 28-years-old stand (Komlenović 1998), 182 t·ha^{-1} (wood and bark only) in 27-years-old stand (Gower et al. 1991) to 216 t·ha^{-1} in 35-36-years-old stand (Eriksson, Rosen 1994, temperature of drying 105°C). Li et al. (2003) found a relationship between aboveground biomass and elevation in larch stands in Tyrol (Austria). European larch stands (27-years-old) situated at the elevation of 1,680, 1,810 and 1,940 m a.s.l. showed aboveground biomass (without stumps) 135 t, 61 t and 20 t per hectare, respectively.

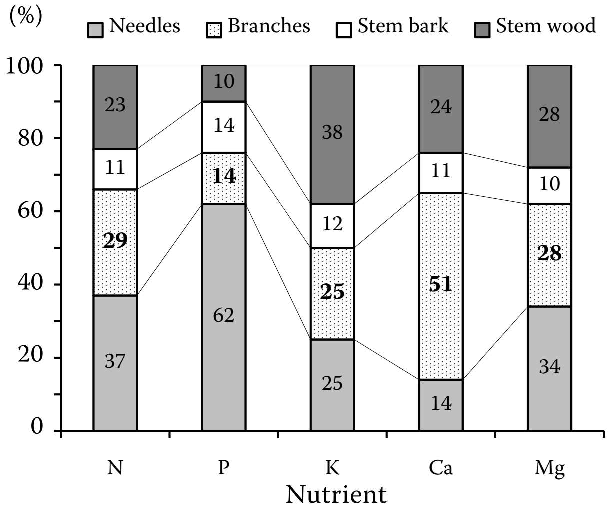

Fig. 4. Location of nutrient amount in above-ground biomass by tree parts of larch stands at the age of 20 years on Control variant of experiment Kalek in the Krušné hory Mts.

As mentioned above, the difference is caused mainly by stand density, age and sometimes by different ecotypes or subspecies (including hybrids). Therefore, our allometric equations did not compare favourably with equations available in the literature and we agree with the recommendation of Gower et al. (1987), who suggested that discretion must be exercised when applying regression equations to other areas than where they were developed.

Despite the former and current air-pollution load and raking of forest floor before planting, the amount of aboveground biomass produced by substitute larch stands after 20 years is comparable with the results observed in larch stands in other undisturbed sites.

In our study, stemwood was the most important part (59%) of aboveground biomass. Together with stem bark, this part (stem without branches) accounted for 66% of the aboveground biomass in unthinned larch stand. Similar results, i.e. stem wood and bark as dominant parts of aboveground biomass in larch stands, were reported by Young et al. (1980, in Burrows et al. 2003) and Eriksson and Rosen (1994). However, complete stem (wood and bark) represented 80–90% of total aboveground biomass in these studies. Our values are lower probably due to the young age of observed larch stands because the ratio between stem and other parts of biomass will change at older age.

We can compare our results with our previous study in 22-years-old blue spruce substitute stand in the Krušné hory Mts. (Slodičák, Novák 2008). The ratio between stem and other parts of trees in the framework of aboveground biomass was 34% and it means about 19 $t \cdot ha^{-1}$ in comparison with more than 67 $t \cdot ha^{-1}$ in larch stands described in this study. Therefore, European larch can fulfil the wood-production function together with other functions as substitute tree species in the conditions of the Krušné hory Mts.

In our study needles represented the mass of 6 $t \cdot ha^{-1}$ (i.e. 6% of aboveground biomass) at the age of 20 years. It means approximately 2.6 kg per tree in the case of density on control plots 2,280 trees per hectare. This amount is lower by a half in comparison with the results of Myre and Camiré (1996) from 19-years-old European larch (5.9 kg per tree). But the observed larch plantation in south-eastern Quebec had lower stand density – 800 trees per hectare.

European larch grows quickly at the young age and the accumulation of biomass and consequently of nutrients in aboveground biomass is higher than in Scots pine and Norway spruce (Materna 1972). In our study, 20-years-old larch stand accumulated 307 kg of N, 21 kg of P, 136 kg of K, 122 kg of Ca and 53 kg of Mg per hectare. Eriksson and Rosen (1994) reported 318 kg of N, 127 kg of P, 179 kg of K, 111 kg of Ca and 51 kg of Mg in 35-36-years-old stands of *Larix leptolepis*. The values are comparable with the exception of phosphorus, but the amount of this nutrient is relatively changeable in cycling and for example phosphorus from litter is released immediately (Prescott et al. 1993). On the other hand, we observed a similarly lower amount of phosphorus (28 $kg \cdot ha^{-1}$) in blue spruce stands in the Krušné hory Mts. (Slodičák, Novák 2008). Other amounts of nutrients in blue spruce stand were comparable (336 kg of N, 138 kg of K and 159 kg of Ca per hectare) with the larch stand with the exception of Mg. The amount of this nutrient was about 89% higher (53 $kg \cdot ha^{-1}$) in larch stand compared to blue spruce stand (28 $kg \cdot ha^{-1}$).

Possible nutrient losses as a result of thinning can be evaluated taking into account the biomass accumulated in the forest floor under investigated stands. Some studies (e.g. Podrázský, Ulbrichová 2004) showed that European larch appeared as a site degrading species.

Research, focused on litterfall under larch stand, was conducted in 2002–2005 (age of 15–18 years) in Kalek experiment in the Krušné hory Mts. (Novák et al. 2006). Mean annual litterfall represents about 3.4 thousand $kg \cdot ha^{-1}$ of dry biomass; it means annually 44 kg of N, 3 kg of P, 4 kg of K, 7 kg of Ca and 4 kg of Mg per hectare. Thus, the amount of nutrients in litterfall is lower compared to their contents in green needles. It corresponds with the results reported by Materna (1972) and Myre and Camiré (1996) about seasonal variations in needle nutrient concentrations in larch stands. In a part of vegetation season (May–October) the amount of N, P and K decreased while the amount of Ca and Mg in needles was stable or it increased. On the other hand, significant increases in the concentrations of N and P and relatively stable concentrations of all nutrients were observed in branch shoots. Thus, larch trees translocate important nutrients from needles to branch shoots before the fall of needles in autumn. It is important from the aspect of possible removal of aboveground biomass from thinning for chipping. On the basis of presented results we can recommend only removing of stems by thinning. All other components (mainly needles and branches) are important sources of nutrients during decomposition. The removal of these parts of trees from forest ecosystems in areas previously degraded by acid deposition may result in calcium and magnesium deficiency because of their low content in forest soil. Additionally, our experimental site was prepared before planting by mechanical raking of slash to rows and the forest floor was created newly again after planting.

On the other hand, thinning supported the faster growth of left trees and consequently faster biomass and nutrient accumulation. In spite of the fact that 53% of trees (accounting for 46% of basal area) were removed at the age of 13 years, seven years after thinning the total aboveground biomass and nutrient content in biomass on thinned plot represented 75% of the values calculated for control unthinned plot.

On the basis of presented research in European larch experiment Kalek in the Krušné hory Mts. (northern part of the CR) we can conclude:

– Aboveground biomass of investigated substitute unthinned larch stand represented approximately 102 thousand kg of dry matter per ha at the age of 20 years. Stemwood (ca 59%) is the most important part of aboveground biomass. Needles, live and dead branches accounted approximately for 6%, 17% and 11% and stem bark only for 7%.
– Total aboveground biomass on thinned plot amounted to 76.2 thousand kg·ha^{-1} in seven years after thinning, i.e. 75% compared to control plot.
– At the age of 20 years, the investigated substitute unthinned larch stand accumulated: nitrogen – 307 kg, phosphorus – 21 kg, potassium – 136 kg, calcium – 122 kg, magnesium – 53 kg per hectare. In the thinned stand, we determined the value lower by about 25% (225 kg of N, 16 kg of P, 102 kg of K, 90 kg of Ca and 39 kg of Mg).

Thinning with consequent removal of aboveground biomass may result in nutrient losses. Especially, the removal of whole tree biomass by thinning for chipping in areas previously degraded by acid deposition may result in calcium and magnesium deficiency because of their low content in forest soil. On the other hand, thinning supported the faster growth of trees left after thinning and consequently faster biomass and nutrient accumulation.

We can recommend to use larch stems only for chipping in the framework of thinning. Other aboveground biomass (mainly needles and branches) should be left in a forest ecosystem for decomposition in conditions of the historically disturbed area of the Krušné hory Mts.

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Received for publication March 1, 2010
Accepted after corrections May 13, 2010

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