Nutrients in the aboveground biomass of substitute tree species stand with respect to thinning – blue spruce (*Picea pungens* Engelm.)

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ABSTRACT: The present paper is the first contribution from the biomass quantification series which is realized by Forestry and Game Management Research Institute in the Krušné hory Mts. (Northern Bohemia). This study is aimed at blue spruce substitute stands. Research was done within the blue spruce experiment Fláje II in the Krušné hory Mts. (800 m above sea level in the spruce forest vegetation zone, acidic category). Results showed that the aboveground biomass of the investigated substitute blue spruce stand without thinning amounted to approximately 56 thousand kg of dry matter per ha at the age of 22 years. Wood and bark of branches are the most important parts of the aboveground biomass (ca 40%). Needles and stem wood accounted for approximately 26 and 28% and stem bark only for 6%. At the age of 22 years, the investigated substitute blue spruce stand accumulated: N – 336 kg, P – 28 kg, K – 138 kg, Ca – 159 kg, Mg – 28 kg per hectare. Thinning with the consequent removal of aboveground biomass (54% of trees, 40% of basal area at the age of 16 years) represented a loss of ca 8.7 thousand kg/ha of total biomass, which contained 53 kg of N, 5 kg of P, 22 kg of K, 26 kg of Ca and 4 kg of Mg. The removal of biomass in areas previously degraded by acid deposition may result in the deficiency of Ca and Mg 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.

Keywords: aboveground biomass; blue spruce; *Picea pungens* Engelm.; Krušné hory Mts.; thinning; substitute stands

Forest stands of substitute tree species were established in the Czech Republic on those sites where the declining spruce monocultures could not be replaced by ecologically suitable tree species. The largest localities with substitute tree species stands are in the Krušné hory Mts. (Northern Bohemia), which have been considered as one of the most heavily air-polluted areas since the sixties of the last century.

In the Forest Region of the Krušné hory Mts., the substitute tree species stands took up about 36% of forest land area (UHÚL 2007), i.e. about 41 thousand ha. The largest percentage of this area is covered with birch (*Betula* sp. – 12.4 thousand ha) and blue spruce (*Picea pungens* Engelm. – 8.9 thousand ha) or mixtures of these two species.

In the Krušné hory Mts., the newly planted substitute tree species stands cannot provide the forest production function. But due to an air pollution decrease, substitute stands are presently in the good health condition and grow relatively well. Consequently, they are nowadays at the beginning of a tree species conversion in the Krušné hory Mts. In connection with the substitute stand conversion there have arisen new questions: (a) Is it possible to remove aboveground biomass from thinning for chipping? and (b) Does the production of chipping

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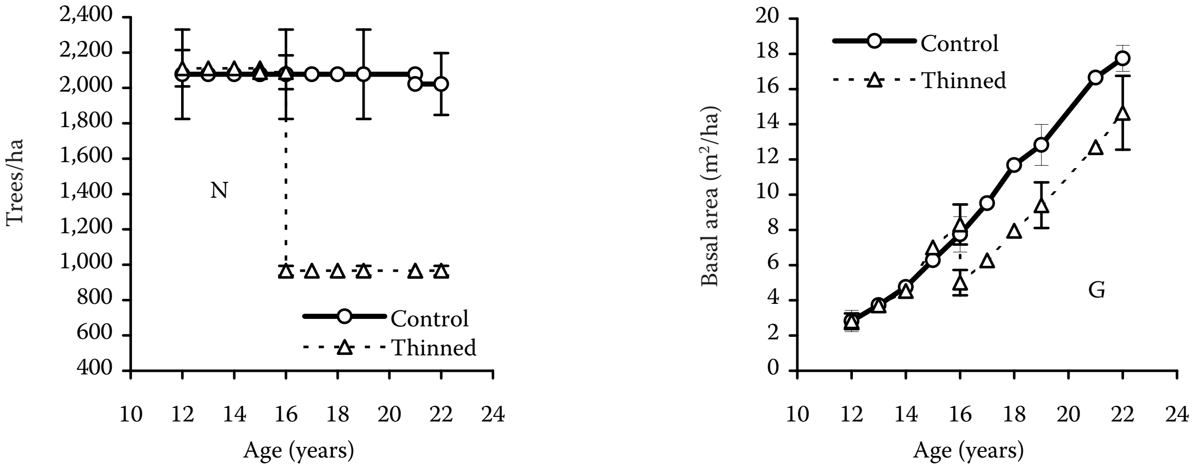

Fig. 1. Number of trees and basal area (mean ± standard deviation) of the blue spruce stand of experiment Fláje II in the Krušné hory Mts.

not mean heavy nutrient losses for trees left within the stand (with respect to their effects on the forest environment, especially in these heavily disturbed forest ecosystems)?

Therefore, we focused on three topics: (1) Quantification of aboveground biomass in substitute blue spruce stands in the Krušné hory Mts., (2) Detection of the amount of main nutrients in the aboveground biomass of blue spruce stands and (3) Evaluation of nutrient losses after removing a part of aboveground biomass by thinning.

Blue spruce is the first of the introduced tree species used for regeneration of clearcuts induced by air pollution since 1967–1968 in the Krušné hory Mts. (Šika 1976). In contrast with the original habitat in the West of the USA where blue spruce creates unclosed mixed stands, young monocultures (thickets) of blue spruce in the Krušné hory Mts. create closed-canopy stands with unsatisfactory stability and frequent damage by climatic factors (mainly top breaks or windfalls, frost damage, etc.). Deformations and damage of the root system are frequent as well. Furthermore, an adverse effect of blue spruce stands on the forest soil was observed (Podrázský et al. 2003). On the other hand, the present blue spruce stands comply with main objectives of cultivation of substitute tree species stands, i.e. they create more favourable growing conditions for the gradual regeneration of forest stands by target tree species (Balcar, Kacálek 2003).

MATERIAL AND METHOD

Research was done on the thinning experiment Fláje II (Slodičák, Novák 2001) established in 1996 in the summit part of the Krušné hory Mts. The blue spruce stand is situated on a southern gentle slope, 800 m above sea level in the spruce forest vegetation zone (acidic category). The experimental series consists of three comparative plots 0.1 ha in size, each divided into ten 100 m^2 partial plots for statistical evaluation. The samples were taken on the control plot without thinning only. The experimental stands have been measured (diameter at breast height, height, health condition) annually since 1996. The crown area covered 91% of the stand area at the age of 16 years in 2000. Full coverage of land by crowns (full canopy) was attained in the vegetation period 2001 (Novák, Slodičák 2006). During the period of investigation, the number of trees was practically unchanged (2,078–2,022 trees/ha) on the control plot without thinning (Fig. 1). On a plot with thinning, 54% of trees (40% of basal area) were removed by this measure at the age of 16 years. Basal area on the control plot increased approximately six times during the period of observation (at the age of 12–22 years).

In autumn 2005 (age of 21 years), the diameter structure of blue spruce stand on the control variant was evaluated and 6 sample trees were chosen for destructive biomass analysis. The sample trees were felled and measured in 2006. Besides the common measuring of stem volume (length, diameter by sections), we collected data on the diameter of branch base (for all branches). For laboratory analyses (dry biomass and nutrient content of needles, bark and wood) sample branches (from 1^{st}, 2^{nd}, 3^{rd}, 5^{th}, 7^{th}, 9^{th}, etc. whorl) and wood samples (from each stem) were used.

All samples were dried first in the open air and afterwards in a laboratory at 70°C and weighed. Nutrient content was assessed (after mineralization by mineral acids) from composite samples from each

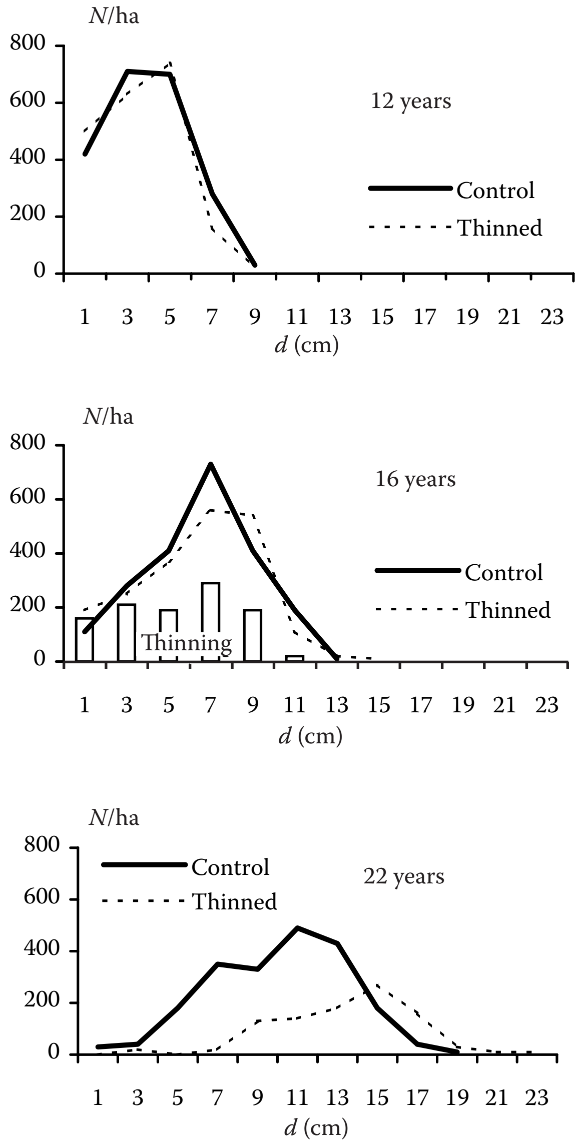

Fig. 2. Diameter structure of blue spruce stands at the age of 12, 16 and 22 years in two variants (control and thinned) of experiment Fláje II in the Krušné hory Mts.

fraction (branches – i.e. a mixed sample of wood and bark of branches, needles, stem wood and stem bark). Total nitrogen (N) concentration was analyzed 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 the addition of 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 the dependence between diameter at breast height and observed variables. Relationships between diameter at breast height and dry weight of biomass components of forest trees were found to be strong in many studies (e.g. Korsuň 1964; Petráš et al. 1985; Černý 1990; Hochbichler et al. 2006). Based on the real diameter structure of control stand in the period of 1996–2005 (age of 12–21 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 (diameter structure – Fig. 2) from real thinning which was done at the age of 16 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 throughout.

RESULTS

Calculation and quantification of aboveground biomass on control plot

Relationships between diameter at breast height and dry biomass were calculated for the investigated parts of blue spruce individuals – needles, branches, stem wood and stem bark (Fig. 3). Quantification of dry mass at the stand level was done using the constructed equations. During the period of investigation (age of 12–21 years) the total biomass of investigated stand increased from 6.1 to 56.2 thousand kg of dry matter per hectare on the control plot without thinning (Table 1).

The biomass of needles and stem wood was more ore less the same – at the age of 22 years it amounted approximately to 14.4 and 15.8 tons per hectare (i.e. 26 and 28% of total biomass). The lower proportion of biomass was found in the stem bark fraction – from 0.6 to 3.1 thousand kg/ha, and it accounted for 6% of total biomass at the age of 22 years. The most important part of biomass was represented by branches (wood and bark) which increased from 2.5 to 22.9 thousand kg/ha during the period of observation, accounting for 40% of total biomass at the age of 22 years.

Amount of main nutrients in aboveground biomass on control plot

Nutrient content in total biomass was calculated for the present study (Table 1). During the period of observation (age of 12–22 years) the amount of N increased from 38 to 336 kg/ha. The amounts of Ca and K in aboveground biomass were similar and increased from 19 to 159 and from 16 to 138 kg/ha, respectively. P and Mg accounted for the lower proportion in accumulated aboveground biomass in the whole period of investigation (from 3 to 28 kg/ha).

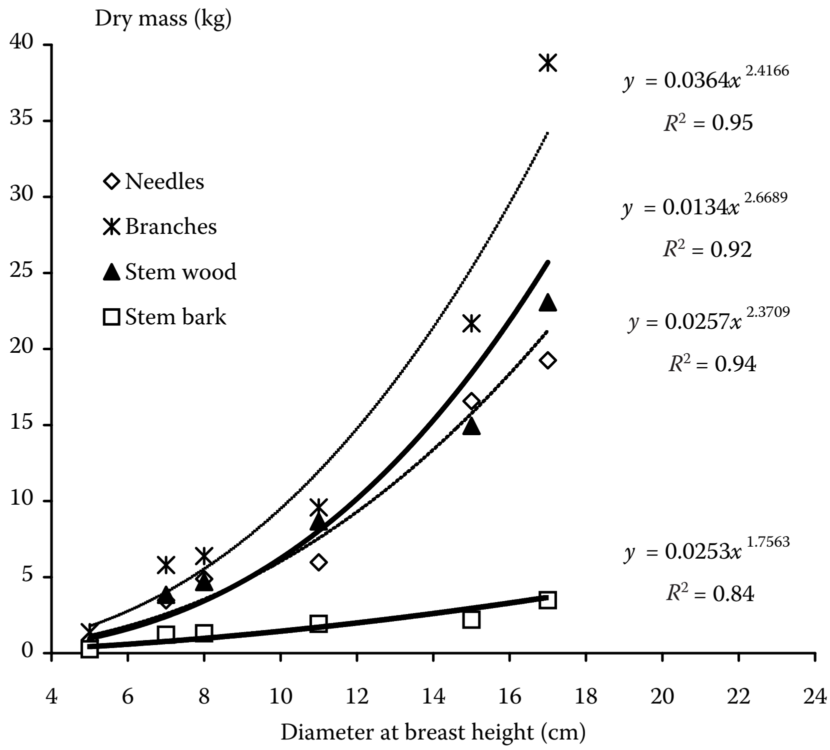

Fig. 3. Relationship (by six sample trees) between the diameter at breast height and dry mass of observed particular parts in the blue spruce stand of experiment Fláje II in the Krušné hory Mts.

During the ten years (age of 12–22 years) the total biomass and consequently the content of N, P, K and Mg increased approximately nine times. The content of Ca increased about eight times only in the same period.

Nutrient loss after the removal of a part of aboveground biomass by thinning

Thinning with consequent removal of aboveground biomass may result in nutrient losses (Table 1). A reduction (54% of trees represented 40% of basal area) was done at the age of 16 years. This thinning resulted in a loss of ca 8.7 thousand kg/ha of total biomass, which contained 53 kg of N, 5 kg of P, 22 kg of K, 26 kg of Ca and 4 kg of Mg. Before thinning (at the age of 16 years), the plot with thinned stand reached 100–110% of aboveground biomass and nutrient content in comparison with the control plot. This ratio was decreased by the thinning to the level 64–68%. Six years later (at the age of 22 years), total aboveground biomass and nutrient content in biomass on the thinned plot represented 89–92% of the values calculated for the control plot without thinning.

DISCUSSION AND CONCLUSION

The aboveground biomass of the investigated substitute blue-spruce stand amounted to approximately 56 thousand kg of dry organic matter per ha at the age of 22 years. Similar studies of young Norway spruce (*Picea abies* [L.] Karst.) stands were published in the Czech Republic. Results of these studies showed higher values of aboveground biomass – 14-years-old stand ca 65 t/ha (Chroust 1993), 20-years-old stand ca 85 t/ha (Chroust, Tesařová 1985) or 24-years-old stand ca 79 t/ha (Vyskot 1980). The difference is caused mainly by stand density (more than 4 thousand Norway spruce trees per hectare in comparison with ca 2 thousand blue spruce trees per hectare in our study) and consequently by different characteristics of mean stem. Generally, the mean stem of blue spruce stand was shorter, but thicker than the mean stem of Norway spruce.

In our study, wood and bark of branches (ca 40% together) are the most important parts of the aboveground biomass. Needles accounted for approximately 26% and stem wood and stem bark for 28% and 6%, respectively (i.e. complete stem 34%). In contrast, presented analyses from Norway spruce stands (Chroust, Tesařová 1985; Chroust 1993) showed the stem (wood + bark) as the most important (ca 40%) part of the aboveground biomass. Both the other parts – needles and branches – represented approximately 30% of the total aboveground biomass. This ratio changes for Norway spruce at later age. Konôpka and Zilinec (1999) published that the aboveground biomass in a 60-years-old Norway spruce stand was composed of 74% of stem and

Table 1. Development of aboveground biomass and nutrient content in this biomass (kg/ha) of blue spruce stand at the age of 12–22 years in variants (C – control, T – thinned) of experiment Fláje II in the Krušné hory Mts.

Age (year)	Variant	Biomass components								Total biomass		Nutrients in total biomass									
		stem wood		stem bark		branches		needles				N		P		K		Ca		Mg	
		C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T
12	mean	1,382	1,430	601	610	2,479	2,552	1,625	1,671	6,087	6,263	38	39	3	3	16	16	19	20	3	3
(1996)	*S.D.*	*445.8*	*335.9*	*161.0*	*102.0*	*761.7*	*552.0*	*494.7*	*355.8*	*1,863.2*	*1,345.4*	*11.6*	*8.3*	*1.0*	*0.7*	*4.8*	*3.4*	*5.7*	*4.0*	*1.0*	*0.7*
16	mean	5,281	5,868	1,506	1,598	8,451	9,272	5,424	5,938	20,663	22,676	127	138	11	12	52	57	61	67	11	11
(2000)	*S.D.*	*842.2*	*1,265.7*	*252.1*	*249.9*	*1,372.6*	*1,852.4*	*883.6*	*1,168.9*	*3,349.1*	*4,536.3*	*20.6*	*27.1*	*1.8*	*2.3*	*8.5*	*11.2*	*10.0*	*12.8*	*1.7*	*2.2*
16 (2000)	mean		3,675		941		5,716		3,649		13,980		85		7		35		41		7
After T*	*S.D.*		*834.3*		*154.4*		*1,198.7*		*753.9*		*2,940.8*		*17.5*		*1.5*		*7.2*		*8.2*		*1.4*
22	mean	15,779	15,218	3,141	2,450	22,888	20,852	14,430	13,010	56,237	51,529	336	303	28	25	138	125	159	142	28	25
(2006)	*S.D.*	*154.8*	*3,399.1*	*160.0*	*387.1*	*501.0*	*4,280.9*	*346.7*	*2,628.3*	*1,161.9*	*10,695.2*	*8.0*	*61.2*	*0.7*	*5.3*	*3.3*	*25.2*	*4.1*	*28.3*	*0.7*	*5.1*

*after thinning, *S.D.* – standard deviation

26% of branches + needles. Slightly different values were published by Černý (1990) for a 57-years-old Norway spruce stand (stem wood and bark 83%, needles and branches 17%) and by Vyskot (1980) for 52-years-old (stem wood and bark 86%, needles and branches 14%) and 68-years-old (stem wood and bark 80%, needles and branches 20%) Norway spruce stands. On the other hand, total weight of needle biomass increased continually with the age in Norway spruce stands (Petráš 1985).

Possible nutrient losses by thinning can be evaluated taking into account the biomass accumulated in the forest soil under investigated stands. Research focused on humus horizons under blue spruce stand was done in 2002 in this experiment Fláje II (Ulbrichová et al. 2005). Forest-floor humus horizons (L + F + H) represent 82,000 kg/ha of dry biomass, it means 1,035 kg of N, 83 kg of P, 158 kg of K, 15 kg of Ca and 19 kg of Mg per hectare. Taking into account the nutrients accumulated in humus horizons under investigated stands, the problem of N, P and K is not probably urgent (humus is rich in these nutrients and P has a large mobility). The removal of biomass in areas previously degraded by acid deposition may result in the deficiency of Ca and Mg because of their low content in forest soil. This hypothesis is partly supported by our results from this study. While the total biomass and consequently the content of N, P, K and Mg increased approximately nine times during the ten years (age of 12–22 years), the content of Ca increased about eight times only in the same period.

On the other hand, thinning supported the faster growth of trees left after thinning and consequently faster biomass and nutrient accumulation. Six years after thinning total aboveground biomass and nutrient content in the biomass on the thinned plot represented 89–92% of the values calculated for the control plot without thinning.

On the basis of presented research, which was done within the blue spruce experiment Fláje II in the Krušné hory Mts. (North Bohemia), it can be concluded:

The aboveground biomass of the investigated substitute blue-spruce stand without thinning amounted to approximately 56 thousand kg of dry matter per ha at the age of 22 years. Wood and bark of branches (ca 40%) are the most important parts of the aboveground biomass. Needles and stem wood represented approximately 26 and 28% and stem bark only 6%.

At the age of 22 years, the investigated substitute blue spruce stand without thinning accumulated: N – 336 kg, P – 28 kg, K – 138 kg, Ca – 159 kg, Mg

– 28 kg per hectare. During the ten-year period of investigation (age of 12–22 years) the total biomass and consequently the content of nutrients increased approximately eight to nine times.

Thinning with the consequent removal of aboveground biomass may result in nutrient losses. Especially, the removal of biomass by thinning for chipping in areas previously degraded by acid deposition may result in the deficiency of Ca and Mg 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.

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Živiny v nadzemní biomase porostů náhradních dřevin ve vztahu k výchovným zásahům – smrk pichlavý (*Picea pungens* Engelm.)

ABSTRAKT: Práce je první analýzou nadzemní biomasy ze série realizované Výzkumným ústavem lesního hospodářství a myslivosti v oblasti Krušných hor a je zaměřena na náhradní porosty smrku pichlavého. Výzkum proběhl na experimentu s výchovou smrku pichlavého Fláje II v Krušných horách (800 m n. m., SLT 8K). Výsledky ukazují, že ve věku 22 let je v náhradním (dosud nevychovávaném) porostu smrku pichlavého akumulováno přibližně 56 tun sušiny na hektar. Nejdůležitější částí nadzemní biomasy je dřevo a kůra větví (asi 40 %). Jehličí a dřevo kmene reprezentují přibližně 26 a 28 % a kůra kmene pouze zbývajících 6 %. Ve věku 22 let akumuluje hektar sledovaného porostu smrku pichlavého: 336 kg dusíku, 28 kg fosforu, 138 kg draslíku, 159 kg vápníku a 28 kg hořčíku. Výchovný zásah spojený s odstraněním nadzemní biomasy (54 % stromů, 40 % výčetní základny ve věku 16 let) reprezentoval ztrátu na hektar asi 8,7 tun celkové biomasy, která obsahovala 53 kg N, 5 kg P, 22 kg K, 26 kg Ca a 4 kg Mg. Odstraňování biomasy v oblastech s předchozí degradací kyselými depozicemi může směřovat k nedostatku Ca a Mg díky jejich nízkému obsahu v těchto lesních půdách. Naproti tomu výchovné zásahy podporují rychlejší růst ponechaných stromů a tím i rychlejší akumulaci biomasy a živin.

Klíčová slova: nadzemní biomasa; smrk pichlavý; *Picea pungens* Engelm.; Krušné hory; výchova porostů; porosty náhradních dřevin

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