Aboveground biomass of substitute blue spruce stands in the Ore Mountains

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Abstract
Presented paper is focused on quantification of aboveground biomass in substitute blue spruce (*Picea pungens* Engelm.) stands in the Ore Mts. (Northern Czechia) by the method of sample trees felled and measured at the age of 21 years. Besides the classical measuring of stem volume (length, diameter by sections), we collected data about diameter of branch base (for all branches). For laboratory analyses (dry biomass and nutrient content of needles, bark and wood) sample branches and wood samples were used. Results showed that total aboveground biomass on control variant increased from ca 7 thousand kg.ha^{-1} (at the age of 12 years) to 55 thousand kg.ha^{-1} (at the age of 21 years). Consequently in the Ore Mts., one hectare of twenty-year-old blue spruce stands represents (in dry biomass): about 15,000 kg of stem wood, 3,000 kg of stem bark, 22,000 kg of branches and 14,000 kg of needles. In particular fragments of accumulated aboveground biomass there are 326 kg of N, 28 kg of P, 132 kg of K and 27 kg of Mg per hectare.

Introduction

The Ore Mts. (Northern Czechia) has been one of the most heavily air-polluted areas since the sixties of the last century. Therefore, forest stands of substitute tree species were established on the sites where the declining spruce monocultures could not be replaced by ecologically suitable tree species. The largest percentage of this area is covered with birch (*Betula sp.*) and blue spruce (*Picea pungens* Engelm.) or mixtures of both two species.
Blue spruce is first of introduced tree species used for regeneration of clearcuts induced by air pollution since 1967-1968 in the Ore Mts. (Šika 1976). Young monocultures (thickets) of blue spruce are relatively frequent in the Ore Mts. in contrast to original habitat in the West of USA where blue spruce creates unclosed mixed stands. In the Ore Mts., closed-canopy stands do not have satisfactory stability and they are frequently damaged by climatic factors (mainly top breaks or windfalls, frost damage, etc.). Deformations and damage of root system are common as well. Furthermore, adverse effect of blue spruce stands on forest soil was found (Podrázský et al. 2003). On the other hand, present blue spruce stands satisfy main objectives of stands of substitute tree species cultivation, i.e. they create more favourable growing conditions for gradual regeneration of forest stands by target tree species.

In the Ore Mts., the forest management is totally influenced by deforestation, which was caused via air pollution in history. Newly planted substitute tree species stands cannot supply forest production function. But due to air pollution decrease substitute stands are presently in good health condition and grow well. Consequently, they are nowadays at the beginning of tree species conversion in the Ore Mts. In connection with substitute stand conversion new questuions appeared: (a) Is it possible to remove aboveground biomass from thinning for chipping? and (b) Does production of chipping not mean heavy nutrient losses for trees left within the stand (with respect to their effects of forest environment, especially in this heavily disturbed conditions)?

Therefore, the objectives of the study are: (1) Quantification of aboveground biomass in substitute blue spruce stands in the Ore Mts., (2) Detection of the amount of main nutrients in aboveground biomass of blue spruce stands and (3) Evaluation of the nutrient loss after removing a part of aboveground biomass by thinning.

Material and method

Research was conducted within thinning experiment Fláje II (Slodičák, Novák 2001), established in 1996 in the top part of the Ore Mts. The blue spruce stand is situated on southern gentle slope, 800 m above sea level in the Spruce forest vegetation zone (acidic category). Experimental series consists of three comparative plots with the area of 0.1 ha , each divided into ten 100 m^2 partial plots for statistical evaluation. The samples were taken within control unthinned plot only. The experimental stands have been measured (diameter at breast height, height, health condition) annually since 1996. The crown area covered 91% of stands area at the age of 16 years in 2000. Full coverage of land by crowns (full canopy) was attained in vegetation period 2001. Investigated control stand was described by following characteristics in Tab. 1 (Novák, Slodičák 2006). During the period of investigation, number of trees was unchanged and basal area, mean diameter and mean height increased approximately six, three and two times, respectively.

Tab. 1: Basic characteristics (mean ± standard deviation) of control unthinned stand of experiment Fláje II in the Ore Mts.

Index	Age of 12 years (1996)	Age of 21 years (2005)
Number of trees per 1 ha	2078±253	2078±253
Basal area in $m^2.ha^{-1}$	2.8±0.6	16.7±1.1
Mean diameter in cm	4.1±0.3	10.3±0.3
Mean height in m	2.5±0.1	5.4±0.1

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

All samples were dried first in open air and afterward in laboratory at 70 °C and weighted. Nutrient content was assessed (after mineralization by mineral acids) from composite samples from each fraction (branches - means mixed sample of wood and bark of branches, needles, stem wood and stem bark). Total Nitrogen (N) concentration was analyzed by Kjehldahl 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.

From the analyses of the data from field measuring of sample trees (number and diameter of branches, stem wood volume, stem bark volume) and the data from 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 as strong in many studies (e.g. Korsuň 1964, Černý 1990, Hochbichler et al. 2006). Based on real diameter structure of the control stand at the period of 1996 – 2005 (age of 12 – 21 years) we assessed: (a) The biomass of particular fractions (including nutrient content) and (b) The total biomass (including nutrient content). In order to evaluate potential effect of biomass removal, we simulated two levels of thinning: 30% and 50% reduction. 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

Quantification of aboveground biomass

During the period of investigation (age of 12 – 21 years) the total biomass of investigated stand increased from 6 to 52 thousand kg of dry matter per one hectare (Fig. 1). Biomass of needles and stem wood was more ore less the same – at the age of 21 years it represented approximately 13 and 14 tons per one hectare (i.e. 26 and 28% of total biomass) during the period of investigation. The lower proportion of biomass was found in the stem bark fraction - from 0.6 to 3 $t.ha^{-1}$, and it represented 6% of total biomass at the age of 21 years. The most important part of the biomass was created by branches (wood and bark) which increased from 2.5 to 21 $t.ha^{-1}$ and represented 40% of total biomass at the age of 21 years.

Amount of main nutrients in aboveground biomass

Accumulated biomass consists of next following macronutrients in observed blue spruce stand. (Fig. 2). During the period of observation (age of 12 – 21 years) amount of Nitrogen (N) increased from 38 to 310 $kg.ha^{-1}$.

Amount of Calcium (Ca) and Potassium (K) in above-ground biomass was similar and increased from 19 to 147 and from 16 to 128 $kg.ha^{-1}$, respectively. Phosphorus (P) and Magnesium (Mg) create the lower proportion of accumulated biomass over all period of investigation (from 3 to 26 $kg.ha^{-1}$).

During the ten years (age of 12 – 21 years) the total biomass and consequently the content of nutrients increased approximately eight times.

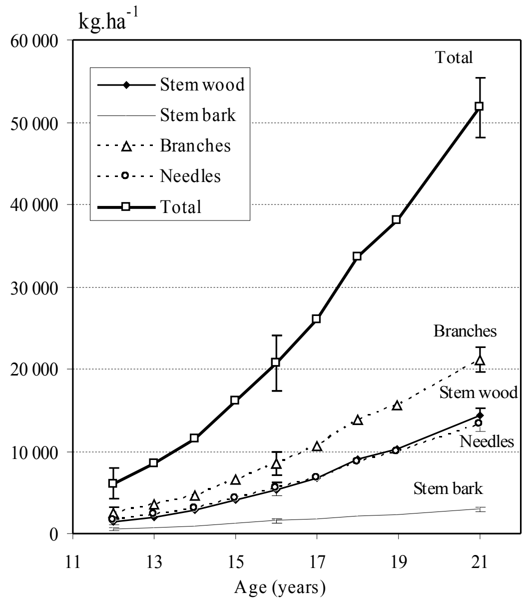

Fig. 1: Above-ground biomass (dry matter in kg.ha^{-1} with standard deviations) of blue spruce stand at the age of 12 – 21 years on control unthinned plot of experiment Fláje II in the Ore Mts.

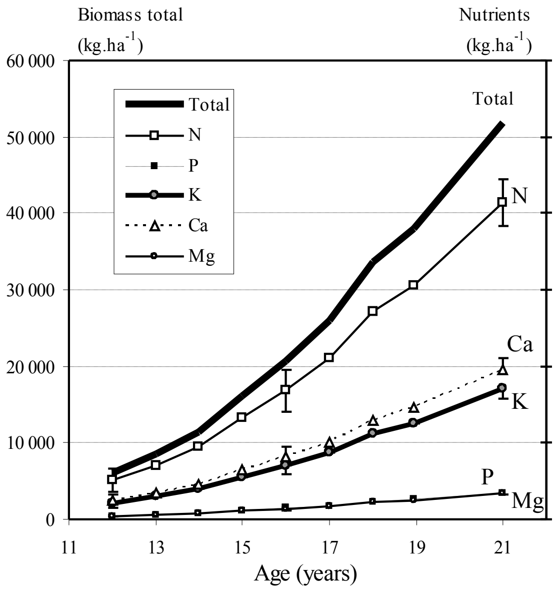

Fig. 2: Nutrients content (in kg.ha^{-1} with standard deviations) in above-ground biomass in comparison with total amount of above ground biomass of blue spruce stand at the age of 12 – 21 years on control unthinned plot of experiment Fláje II in the Ore Mts.

Nutrient loss after removing of part of aboveground biomass by thinning

Thinning with consequent removing of above-ground biomass may result in nutrient losses (Tab. 2). In accordance with presented methods, we simulated two levels of thinning: 30% and 50% reduction for evaluation of potential effect of biomass removal at the age of 21 years. Smaller simulated reduction (removing of 30% of above-ground biomass by thinning) represented loss of ca 15.5 t.ha^{-1} of total biomass, which contained 93 kg of Nitrogen, 8 kg of Phosphorus, 38 kg of Potassium, 44 kg of Calcium and 8 kg of Magnesium. Simulated reduction by half (removing of 50% of above-ground biomass by thinning) represented loss of ca 25.9 t.ha^{-1} of total biomass contained 155 kg of Nitrogen, 13 kg of Phosphorus, 64 kg of Potassium, 74 kg of Calcium and 13 kg of Magnesium.

Discussion and conclusion

Aboveground biomass of investigated substitute blue-spruce stand represented approximately 52 thousand kg of dry organic matter per ha in the age of 21 years. In the Czechia, similar studies in the young Norway spruce stands were published. Results from these studies showed higher values of above ground biomass – ca 65 t.ha^{-1} in 14-year-old stand (Chroust 1993) or ca 85 t.ha^{-1} in 20-year-old stand (Chroust, Tesařová 1985). Difference is caused mainly by

Tab. 2: Aboveground biomass and content of nutrients (in kg.ha^{-1}) with respect to proposed thinning in 21-year-old blue spruce stand in the Ore Mts.

Index		Above-ground biomass	N	P	K	Ca	Mg
		(kg.ha^{-1})					
Total		51 781	310	26	128	147	26
Simulated levels of thinning	- 30%	15 534	93	8	38	44	8
	- 50%	25 891	155	13	64	74	13
Dry mass content in horizons LFH*		82 000	1 035	83	158	15	19

** (Ulbrichová et al. 2005) - sampling in 2002* 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 characteristic of mean stem. Generally, mean stem of blue spruce stand was shorter, but thicker than mean stem of Norway spruce.

In our study, the most important part of the aboveground biomass is wood and bark of branches (ca 40% together). Needles represented approximately 26% and stem wood and stem bark 28% and 6% respectively (i.e. complete stem 34%). In contrast, presented analyses from Norway spruce stands (Chroust, Tesařová 1985, Chroust 1993) showed 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 is changed for Norway spruce at later age. Konôpka and Zilinec (1999) published that aboveground biomass in 60-year-old Norway spruce stand was created by 74% of stem and 26% of branches + needles. Slightly different values were published by Černý (1990) for 57-year-old Norway spruce stand (stem wood and bark 83%, needles and branches 17%).

Possible nutrient losses by thinning we can compare with total amount of dry mass and nutrients 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) represents 82 000 $kg.ha^{-1}$ 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 (Tab. 2). Taking into account the nutrients accumulated in humus horizons under investigated stands, the problem of Nitrogen, Phosphorus and Potassium is probably not urgent (humus is high in these nutrients and Phosphorus mobility). Removing of biomass in areas previously degraded by acid deposition may result in deficiency of Calcium and Magnesium because of their low content in forest soil.

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

- Aboveground biomass of investigated substitute blue-spruce stand represented approximately 52 thousand kg of dry matter per ha at the age of 21 years. The most important part of the aboveground biomass is wood and bark of branches (ca 40%). Needles and stem wood represented approximately 26 and 28% and stem bark only 6%.
- At the age of 21 years, investigated substitute blue spruce stand accumulated: N – 310 kg, P – 26 kg, K – 128 kg, Ca – 147 kg, Mg – 26 kg per hectare. During the ten years period of investigation (the age of 12 – 21 years) the total biomass and consequently the content of nutrients increased approximately eight times.
- Thinning with consequent removal of above-ground biomass may result in nutrient losses. Especially, removal of biomass by thinning for chipping in areas previously degraded by acid deposition may result in deficiency of Calcium and Magnesium because of their low content in forest soil.

Acknowledgements

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