Effect of stand segmentation on growth and development of Norway spruce stands

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ABSTRACT: Segmentation of stands by tracks is often the first phase of forest tending. However, a suitable track width is still discussed in forest practice in the Czech Republic. This article deals with the effect of track width on the growth characteristics of young spruce stands. Research involves several variants of European thinning experiment IUFRO CZ 14 Machov situated in Eastern Bohemia. Totally 3 variants were analyzed: 1 – non-segmented control plot without thinning and plots with forest tending (at top height 10 and 20 m) and with different present width of tracks (plot 3 – originally 3.5 m, plot 4 – originally 5.0 m). The significantly positive effect of stand segmentation and tracks on dbh and crown length was found only for individuals growing in the first row next to a track. As regards the stand volume and volume of mean stem, differences between variants with skidding track (3 and 4) were found minimal and insignificant. Therefore, the observation did not reveal any evident losses of production caused by different widths of skidding tracks.

Keywords: Norway spruce; forest tending; skidding track; growth; production; static stability

Tending of forest stands is an important silvicultural measure directed at development of forest stands in terms of their production and non-production functions. Segmentation of stands by tracks is often the first phase of forest tending. As various logging techniques can be used, skidding tracks must be adapted to the particular technical parameters above all to the wheel gauge of machinery. Segmentation of tended stands (by skidding tracks or slope roads) enables also their accessibility, makes skidding easier when using machinery, enhances resistance against abiotic factors and substantially reduces damage to natural regeneration (e.g. Bezecný et al. 1992). Higher increment of track-neighbouring trees was also reported (e.g. Eriksson 1987; Chroust 1997).

However, a suitable track width is still discussed in forest practice. Foresters are frequently worried about losses of production due to excessively wide skidding tracks. The common width of skidding track is approximately 3–4 m, max. 5 m (Ronay, Bumerl 1982). Additionally, a higher density of the road (track) network is considered to lead to a reduction in productive forest land (Janeček et al. 2001). On the other hand, a higher density of skidding tracks means usually lower losses caused by transport machinery.

Different track widths were also used to design an international IUFRO experiment dealing with the rationalization of young spruce stand tending (Abetz 1977). One part of this series, Machov CZ 14 experi-

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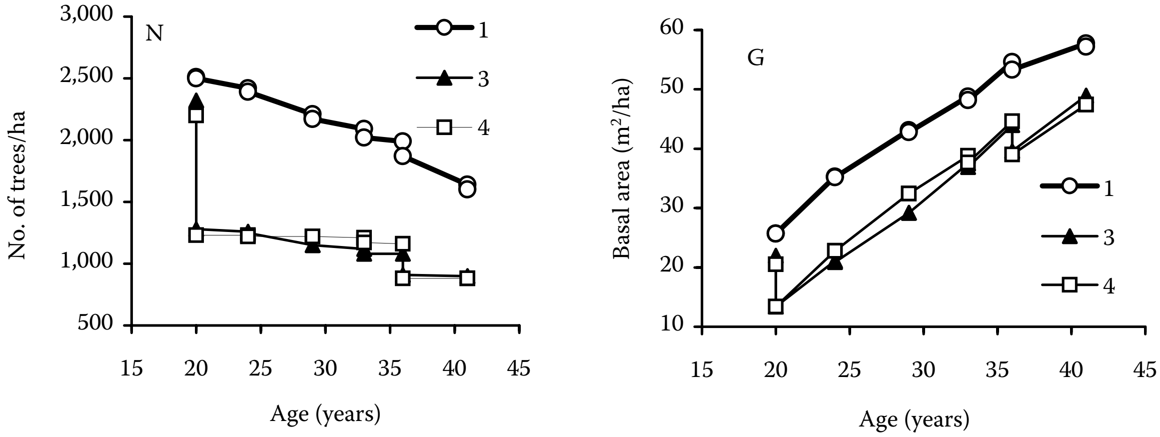

Fig. 1. The number of trees and basal area development in observed plots of spruce thinning experiment IUFRO CZ 14 Machov at the age of 20–41 years (1 – control plot without thinning and tracks, 3 and 4 – plots with thinning and tracks, see Methods for more details)

ment, was established in Eastern Bohemia in 1971 (Chroust 1981).

The aim of our study was to detect possible effects of stand segmentation (using skidding tracks of different width) on the growth and development of experimental Norway spruce stands. The analysis was focused on possible production losses caused by stand segmentation as well.

MATERIAL AND METHODS

Experimental series Machov CZ 14 is situated in Natural Forest Area 024 – Sudeten Piedmont (The Broumovská vrchovina Hills) within the territory of the former forest enterprise Broumov, at present in private ownership (Chroust 1981; Slodičák 1998). The climate of this area is mildly temperate but mostly very wet or wet. Average annual air temperature ranges between 6 and 7°C, average annual sum of precipitation ranges from 700 to 900 mm.

Spruce monoculture is the first forest generation under conditions of the former meadow situated on the plateau at the elevation of 700 m; the stand was planted in 1965 (Slodičák 2006). Soil type is Albeluvisols – Gleysols to Stagnosols, forest type *Abieto-Fagetum illimerosum acidophilum – Carex pilulifera* with possible slight transition to *Piceeto-Fagetum illimerosum acidophilum – Calamagrostis villosa* (Viewegh 2002).

The experimental series Machov was established in a regularly-spaced spruce thicket in 1971. The stand was 6-years-old reaching the top height of 1.2 m with initial density of 7,700 trees per 1 ha. Respecting the programme of international IUFRO experiment, the initial density of the culture was reduced to 2,500 trees/ha. The experimental series consists of five thinning variants, each repeated twice. The plots were designed as rectangles 25 m by 40 m (0.1 ha). The main aim of the experiment has been to test three different thinning strategies compared with two plots (number 1 and 6) left as control. In these plots no tending operations have been conducted; only dead trees were removed (Slodičák 1998).

Three experimental plots were chosen for this study:

- 1 – control plot with the original spacing of 2,500 individuals per hectare, where only dry and broken trees were removed,
- 3 and 4 – plots with very heavy thinning in the young stage followed by postponing further operations into the phase when the stand reaches the top height h_{dom} 20 m. Programme 4 differs from programme 3 only in the simulation of machinery use and consequently in the width of tracks.

Until then (2007, age of 42 years) the following tending operations were done in accordance with the programmes on variants 3 and 4 (Fig. 1):

- h_{dom} being 10 m (age of 20 years, year 1985),
- h_{dom} being 20 m (age of 36 years, year 2001).

These dendrometric characteristics were recorded in each plot: diameter at breast height (dbh in cm) measured in two perpendicular directions (firstly from the East and secondly from the North), height (*h* in m) and crown length (in m). The position of all trees was also surveyed in the chosen plots. dbh data were always acquired using a calliper (with mm calibration). Height and crown length (from the lowest whorl that has at least 3 vital branches to the top of tree) of each tree were measured with the Blume-

Table 1. Characteristics of group of trees, which grow in rows with different distance from central axis of the control plot 1 (age of 41 years)

Row*	Plot 1	Diameter $d_{1.3}$ (cm)	Height (m)	Crown length (m)	Quotient of slenderness	Symmetry of stem in $d_{1.3}$
1 (2.6)	mean	20.90a	19.70a	7.10a	0.960a	0.60a
	S.D.	5.32	2.74	2.72	0.140	0.36
2 (5.2)	mean	19.10a	18.50a	6.00a	1.000a	0.60a
	S.D.	4.87	3.71	2.84	0.180	0.47
3 (7.8)	mean	20.50a	18.60a	6.20a	0.940a	0.60a
	S.D.	4.60	3.02	2.69	0.120	0.44

*Distance from the skidding track (m)

Significant differences ($p \leq 0.05$) are designated by different letters in columns

Leiss altimeter and 4 m pole. Tree position was surveyed using a 50m tapeline, being regarded the fact that trees are planted in rows parallel to the track.

Other variables were calculated from the measured data: slenderness quotient (*h*/*d*) and symmetry of dbh cross-section (calculated as the ratio of dbh from the first measurement to dbh from the second measurement).

We divided each observed variant into four blocks (area of 0.025 ha) to analyze stem volume. The calculation of volume over bark (for each stem) was based on diameter (dbh) and height *h* using tables (Lesprojekt 1952).

The design of IUFRO experiment (Abetz 1977) defines the width of tracks as follows: variant 1 – without track, variant 3–3.5 m and variant 4–5 m. The actual (present) width of tracks was determined by means of surveyed positions of trees (and their rows) and reconstructed axis (centre) of the track in plot 3. The only exception was plot 4, where the track axis did not follow a parallel direction to the rows of trees. Average width of track was calculated according to Finnish methodology (Ulrich et al. 2002) using a 4m measuring rod.

One-way analysis of variance ($p \leq 0.05$) was used to process measured data using the software Statistica.

RESULTS

Contrary to the initial status, different track widths were found in the investigated plots. Except for control plot 11 (no tracks) the track width of 5.6 m was found in plot 3 (initial width of 3.5 m) and 6.8 in plot 4 (initial width of 5 m). Tracks are thus wider than the methodology of the trial demands. The reason is above all that the distance between stems was measured in closing thicket instead of in crowns. However, the present track dimensions can be used to analyze the dependence of investigated variables on the track width.

Table 2. Characteristics of groups of trees which grow in rows at different distance from the skidding track on plot 3 (age of 41 years)

Row*	Plot 3	Diameter $d_{1.3}$ (cm)	Height (m)	Crown length (m)	Quotient of slenderness	Symmetry of stem in $d_{1.3}$
1 (2.8)	mean	27.90a	21.40a	12.50a	0.750a	1.10a
	S.D.	6.58	3.36	2.61	0.100	0.94
2 (5.4)	mean	24.70b	21.10a	10.10b	0.870b	0.80a
	S.D.	4.92	2.57	2.57	0.100	0.81
3 (8.0)	mean	25.00b	21.10a	9.50b	0.830b	0.70a
	S.D.	5.08	2.03	2.54	0.120	0.77

*Distance from the skidding track (m)

Significant differences ($p \leq 0.05$) are designated by different letters in columns

Comparison between rows

It was confirmed in control plot 1 (where no tending and tracks were realized) that no observed variable (dbh, height, crown length, *h*/*d* ratio and symmetry of stem) was significantly influenced by tree position – particularly with respect to a distance from the central axis of the plot (Table 1).

The significantly highest average diameter of individuals (27.9 cm) growing in the first row next to the track was found in plot 3 (track width of 5.6 m) in comparison with individuals situated in more distant rows (the second and the third row – 24.7 and 25.0 cm, respectively, Table 2). Consequently, we found a significantly lower *h*/*d* ratio (0.75) and significantly longer crowns (12.5 m) for trees growing in the first row (next to the track) in comparison with the group of trees from the second and the third row (*h*/*d* ratio 0.87 and 0.83, crown length 10.1 and 9.5 m). The other variables (height and symmetry of stem) were not significantly influenced by tree position.

Similarly, a significantly higher average diameter of individuals (27.7 cm) growing in the first row next to the track was found in plot 4 (track width of 6.8 m) in comparison with individuals situated in more distant rows – the second and the third (26.4 and 23.7 cm, respectively, Table 3). We found significantly longer crowns (11.8 m) for trees growing in the first row (next to the track) in comparison with the group of trees from the second and the third row (11.1 and 8.8 m). On the other hand, the *h*/*d* ratio and height were not significantly influenced by tree position within this variant.

Comparison between variants

In the framework of this study, stand volume (m^3/ha) and volume of mean stem (m^3) were determined in particular variants at the age of 42 years (2007). The highest stand volume (532 m^3/ha) was found in the control unthinned variant 1 (Fig. 2). The stand volume in thinned variants 3 (track width of 5.6 m) and 4 (track width of 6.8 m) amounted to 451 and 469 m^3 per hectare, respectively. Differences between variants with skidding track (3 and 4) were insignificant (p = 0.93).

We observed the lowest volume of mean stem in the control variant 1 (0.35 m^3). On the other hand, the mean stem in thinned variants 3 and 4 reached 0.56 and 0.55 m^3, respectively (Fig. 2). Differences between variants with skidding track (3 and 4) were minimal and insignificant (p = 0.95).

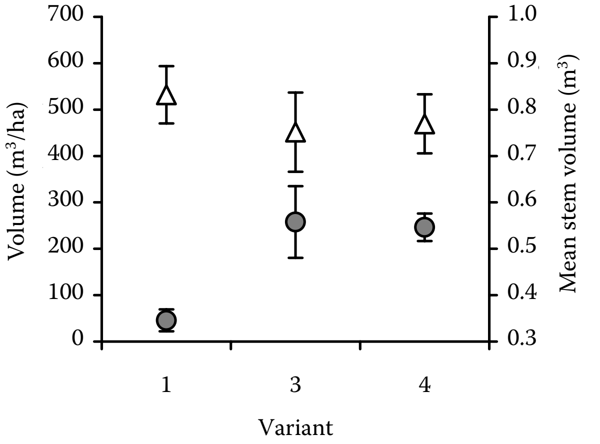

Fig. 2. The values (mean and standard deviation) of stand volume (open triangles) and volume of mean stem (grey circles) of spruce stands in Machov experiment at the age of 41 years (2007). Comparison for three plots: 1 – control plot without thinning and tracks, 3 and 4 – plots with thinning and different widths of tracks (see Methods for more details)

Table 3. Characteristics of groups of trees which grow in rows at different distance from the skidding track on plot 4 (age of 41 years)

Row*	Plot 4	Diameter $d_{1.3}$ (cm)	Height (m)	Crown length (m)	Quotient of slenderness	Symmetry of stem in $d_{1.3}$
1 (2.6)	mean	27.70a	22.10a	11.80a	0.810a	1.40a
	S.D.	4.61	3.60	2.96	0.140	1.14
2 (5.2)	mean	26.40b	22.20a	11.10b	0.860a	0.60b
	S.D.	5.18	2.13	2.57	0.150	0.80
3 (7.8)	mean	23.70c	20.30a	8.80c	0.860a	0.60b
	S.D.	4.39	2.46	2.43	0.120	0.46

*Distance from the skidding track (m)

Significant differences ($p \leq 0.05$) are designated by different letters in columns

DISCUSSION

Tree position in the stand influences the tree diameter increment considerably (e.g. Šebík, Polák 1990). Diameter increases not only in trees directly neighbouring with skidding track but also in more distant trees to a certain extent. Enhancement and width of annual ring then decrease being influenced by the position of the tree related to its increasing distance from the skidding track (Chroust 1997). According to Eriksson (1987) this phenomenon is evident for spruce stands at the age of 16 years up to 3 m from the margin of skidding track. In our study the marginal effect was confirmed for dbh parameter for both variants 3 with skidding track 5.6 m wide up to the first row and for plot 4 with the widest track 6.8 m up to the second row (5.2 m from the track axis). Therefore it is evident that with increasing width of skidding track the space for growth is greater and the marginal effect becomes more intensive. Šebík and Polák (1990) stated in their work that the space extends if available; diameter increment also increases but only to a certain extent. After exceeding an optimal tree spacing no further increment continues.

The statement that the skidding track has no influence on height growth (Niemistö 1989) is quite in accordance with our results that did not prove any significant differences among trees heights related to the distance of the track axis.

This study proved the influence of skidding tracks on the crown length. A longer crown is preserved due to better light conditions (e.g. Forst et al. 1966; Vyskot et al. 1971). The final results from plots 3 and 4 with the widest tracks confirm this fact as well. For plot 4 with the widest skidding track (6.8 m) this fact was observed up to the second row (5.2 m) from the track axis. Average values, however, show a certain trend when the first row reaches the maximum.

It is obvious that dbh values (and consequently the values of height and crown length) for control unthinned variant 1 were lower and thus statistically different in comparison with variants 3 and 4 with skidding tracks. This phenomenon results from tending, and is in accordance with results of Slodičák and Novák (2006), who reported lower values of presented characteristics in the control plot compared to plots 3 and 4 within the experimental series CZ 13 Vítkov (at the age of 40 years) established according to identical methodology like the series CZ 14 Machov.

The value of slenderness quotient is also a very important parameter to assess the static stability of stands. Plot 3 with the value of the quotient 0.75 and plot 4 with the value 0.81 in the first row from the track axis have markedly better slenderness quotients than rows in a more distant position from the track axis and are thus more stable. This result confirms the statement that marginal trees have the lower slenderness quotient, and thus better stability (Vyskot et al. 1971).

Konôpka (1999) distinguished 4 categories of slenderness coefficient according to these values: excellent ≤ 0.82, good 0.83–0.92, satisfactory 0.93 to 1.01 and unsatisfactory 1.02 and higher. As regards the critical level, Korpeľ et al. (1991) considered the value 1.20 and higher as such. According to the above-mentioned studies, the values for trees in the first row from the track axis in plots 3 and 4 are excellent from the aspect of tree stability.

Generally, the values from plots 3 and 4 show excellent mechanical stability in comparison with control plot 1 without tending. This result corresponds with the finding of Slodičák and Novák (2006), who observed that the control plot (without tending) had a worse parameter of static stability at the age of 38 years (h/d = 1.06) than plots with tending and skidding track (h/d around 0.86) in the above-mentioned experiment IUFRO Vítkov.

Coniferous tree species create compression wood with wider annual rings on the leeward to support tree stem and therefore the marginal trees form eccentric stem very often. But eccentricity is also influenced by the one-sidedly formed crown (Vicena et al. 1979). Only plot 4 with the widest skidding track (6.8 m) showed significant differences in stem symmetry in the first row in comparison with more distant rows from the track axis. This plot may be influenced by prevailing winds because its skidding track, the only one of all of them, is situated perpendicularly to the direction of prevailing winds, in contradiction to plot 3 where the skidding track follows the direction of prevailing winds.

Janeček et al. (2001) supposed that losses of production functions of stands are related to the establishment of skidding tracks. On the contrary, our study did not reveal any significant losses in production caused by different width of skidding tracks. Totally per hectare only minimum and insignificant differences in parameters of volume were found on the plots with tracks. This result is proper even when the hitherto felled production, provided on the basis of prescribed tending operations, is added (Slodičák et al. 2005). Results from a similar experiment IUFRO CZ 13 Vítkov, where no provable loss of production related to different width of skidding tracks was found either, were confirmed under conditions of this investigated locality.

CONCLUSION

Based on the analysis of a part of results from the international IUFRO trial CZ 14 Machov investigating the effect of stand segmentation (track width) on production characteristics and static stability of young spruce stands it can be stated:

– Positive effect on growth characteristics was found only for individuals growing in the first row next to the track in variants with tending and with tracks. In this sense, dbh and crown lengths were significantly positively influenced (i.e. they reached the higher values) in variants 3 and 4 with the present track width 5.6 m and 6.8 m, respectively. On the other hand, there was no tree height influenced by tree position in all investigated variants of the trial (average of a row), i.e. by a distance from the track.
– According to the recommended values of *h*/*d* ratio, trees in the first row from the track axis in plots 3 and 4 are excellent from the aspect of tree stability. The effect of track on the slenderness quotient (i.e. better values for trees which grow near the track) was detected in both variants with track, but this effect was significant only for the first row in plot 3 (present track width of 5.6 m).
– Only plot 4 with the widest skidding track (at present 6.8 m) showed significant differences in stem symmetry in the first row in comparison with the other rows more distant from the track axis. Plot 4 was probably influenced by prevailing winds because its skidding track is situated perpendicularly to the direction of prevailing winds, in contradiction to plot 3 where the skidding track follows the direction of prevailing winds.
– Stands without tending and without tracks had the worst parameters (the lowest diameter, height, the shortest crown and the highest slenderness quotient) in comparison with the treated stands (tending and tracks). It is obvious that the absence of thinning is the main reason causing the worse parameters in the control plot.
– We observed no significant losses of production related to various widths of skidding tracks in the investigated plots. Stand volume in thinned variants 3 (track width of 5.6 m) and 4 (track width of 6.8 m) amounted to 451 and 469 m^3 per hectare, respectively. Mean stem in variants 3 and 4 reached 0.56 and 0.55 m^3. Differences between variants were minimal and insignificant.

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Vliv rozčleňování porostů smrku ztepilého na jejich růst a vývoj

ABSTRAKT: Rozčleňování lesních porostů linkami je obvykle první fází výchovných zásahů. V praxi je však v ČR dosud diskutována přiměřená šířka těchto linek. Práce se zabývá zhodnocením vlivu různě širokých linek na růstové charakteristiky mladých porostů smrku ztepilého. Výzkum probíhal na několika variantách Evropského probírkového pokusu IUFRO CZ 14 na lokalitě Machov ve východních Čechách. Celkem byly posuzovány tři varianty: plocha 1 – bez výchovy a bez přibližovací linky a dvě plochy (3 a 4) s výchovou (při horní výšce 10 a 20 m) a s různými šířkami přibližovacích linek (při založení pokusu 3,5 m na ploše 3 a 5,0 m na ploše 4). Průkazný kladný efekt rozčlenění na výčetní tloušťku a délku koruny byl zjištěn pouze u jedinců rostoucích v první řadě u linky. V případě charakteristik produkce (porostní zásoba a hmotnatost středního kmene) zjištěné výsledky ukázaly minimální a neprůkazné rozdíly mezi variantami s různou šíří linek. Na sledovaném experimentu tak nebyly zaznamenány průkazné ztráty na produkci způsobené různou šíří přibližovacích linek.

Klíčová slova: smrk ztepilý; porostní výchova; přibližovací linky; růst; produkce; statická stabilita

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