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Development of the Norway spruce (*Picea abies* /L./ Karst.) stand established by various spacings and affected by abiotic harmful factors and ungulate game

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Abstract: The paper presents the results of 30-year research on silviculture-production relationships in a 50-years-old Norway spruce stand (a small-pole stage) originated from artificial regeneration in a mountain forest. The stand was established in four different spacing variants: (*i*) 1.5 × 1.0 m, (*ii*) 2.5 × 1.0 m, (*iii*) 2.5 × 1.5 m, and (*iv*) 2.5 × 2.5 m. At each spacing, three management methods were investigated: geometric (schematic) intervention, mixed selective intervention, and control (no intervention). The development of the stand was disturbed by repeated snow breaks, rime and ungulate game damage. As a result of these harmful factors, the number of trees has declined markedly, especially in the last decade. This was also confirmed by an insufficient number of target trees in all trial variants. The analysis of quantitative production showed different results in some parameters. We found the most favourable results for the mixed selective method of tending. The 2.5 × 1.5 m spacing with an initial number of 2 667 trees per hectare or the spacing with an even lower number of plants was found to be appropriate under the given conditions.

Keywords: different spacing; snow-break; Norway spruce; target trees; thinning; ungulate game

Norway spruce (*Picea abies* /L./ Karst.) is one of the most significant and, in terms of forest economy, most important tree species both in Slovakia and in the Czech Republic. In Slovakia, it covered 25.5% of the forest land in 2009, so according to the area, it was the second most widespread tree species after the European beech (*Fagus sylvatica* L.) with a share of 31.6% (MPaRV SR 2010). However, in the recent period there has been a decrease in the proportion of Norway spruce (22.7%) in favour of European beech (33.6%) in Slovakia (MPaRV SR 2018). The same trend was observed in other Central European countries, mainly due to the effects of climate change (Hlásny, Sitková 2010; Krejčí et al. 2013; Vacek et al. 2017; Putalová et al. 2019).

In the framework of adaptation and mitigation measures aimed at a reduction in the impacts of the most common climatic extremes (i.e. summer drought, wind storm, precipitation deficit), the focus was mainly on management methods (Schütz 2001; Mason et al. 2012; Hlásny et al. 2017; Slanař et al. 2017; Vacek et al. 2019). Significant and preferred measures also include the conversion of Norway spruce monocultures to mixed stands (Diaci 2002; Gärtner, Reif 2005; Hlásny et al. 2017), especially outside of the native range (Spiecker et al. 2004),

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as well as reconstruction of Norway spruce stands by underplanting deciduous species (Jelínek, Kantor 2006; Knoke et al. 2008; Carnol, Bazgir 2013; Goisser et al. 2013; Saniga, Dendys 2015).

Tending of stands is one of the most important silvicultural measures. In the even-aged stands, it is carried out over a long period of time which usually exceeds half of the stand's rotation period. Many contributions have been devoted to the observation of Norway spruce stand development by various thinning methods (Pařez 1972; Jurča, Chroust 1973; Slodičák 1983; Mráček, Pařez 1986; Laasasenaho, Koivuniemi 1990; Saniga 1996; Chroust 1997; Slodičák, Novák 2007; Slodičák et al. 2010; Dušek et al. 2019). A lot of works compared different methods of tending (schematic, selective, combined schematic-selective intervention) (Chroust 1988; Holodynski 1995; Saniga 1996; Štefančík, Štefančík 2002, Bergström et al. 2006; Štefančík 2012; Štefančík et al. 2012). Based on the results of long-term research, it can be stated that the tending intervention must be carried out in order to increase or strengthen the static stability of stands (Konôpka, Konôpka 2019). The stand stability has to be ensured by applying an intervention in the upper layer with positive selection in the youngest growth stages (thicket and small pole stages). The most vital and usually the thickest trees need to be released, so that their crowns remain free (Slodičák et al. 2010). This is achieved by the method of promising or target (crop) trees. The principle of the above-mentioned methods consists in selection and marking of the required number of such individuals and liberation of their crowns by positive interventions. Approximately 300 to 400 target trees per hectare should be selected in a Norway spruce small pole stage stand with a spacing of 5–6 m (Abetz 1979; Schober 1990; Spellmann, Nagel 1996). When applying the method of promising trees, a twofold number of these trees is recommended (Štefančík 1984). These trees create the stand skeleton that provides favourable static stability with slenderness quotient values below 80 (Slodičák, Novák 2006). In addition, they are also the main bearers of qualitative production of the Norway spruce stand (Štefančík, Štefančík 1993, 2000). A lower number of target trees is exceptional: for example in Belgium, with the initial number of 2 000 individuals per hectare (2.0 × 2.5 m spacing), about 100 target trees per hectare with a spacing of about 10 m were marked (Bednář 2011). Stability of stands is particularly important in pure Norway spruce stands. Indeed, their further development may significantly be jeopardised by unsuitably implemented timeliness and intensity of the intervention (Slodičák et al. 2010; Štefančík 2012; Dušek et al. 2019).

To select the most appropriate tending methods (thinning methods), one of the key issues of their rational management is the determination of the optimal density of young plantations for the artificial regeneration of stands under specific growth conditions (Braastad 1970; Piskun 1972, 1984; Mráček 1983; Prokopjev 1983; Razin 1991; Nilsson 1994). Initial spacing or density of the established young plantation is important for further development of the stand, not only for qualitative production in particular (Kramer et al. 1971; Piskun 1972; Korpeľ, Saniga 1995; Kairiukštis, Malinauskas 2001; Štefančík 2012), but also for the root system development (Jaloviar, Smolek 2004) and quantitative production parameters (Braastad 1979; Korpeľ, Saniga 1995; Štefančík 2013).

Several works have been devoted to the relationship between the initial spacing in Norway spruce young plantations and the growth of young forest stands or small pole and pole stage stands (Braastad 1970, 1979; Mráček, Pařez 1986; Korpeľ, Saniga 1995). Especially the diameter and height development and volume production were observed (Štefančík 2013). In this context, Vyskot's publication (1984) is interesting, in which he assessed the relationship between the production function of the Norway spruce stand and public functions (recreational, hydrological) in relation to its initial spacing.

The aim of this study was to evaluate changes in the stand structure and selected quantitative and qualitative indicators of the 50-years-old Norway spruce stand, depending on different initial spacing and tending method (management) for the period of 30 years, as well as affected by selected harmful factors.

MATERIAL AND METHODS

A Norway spruce stand in the small-pole to pole growth stages was chosen as an object of research in a series of permanent research plots (PRP) Biely Váh – Luksová (eastern Slovakia). The above-mentioned PRPs were originally established to investigate the optimal number of plants per hectare in

https://doi.org/10.17221/18/2020-JFS

Norway spruce stands (Piskun 1972). Later it was followed by research of different tending methods (Štefančík, Štefančík 2002) in stands with different initial number of trees. Detailed description of the natural conditions in PRPs at Biely Váh − Luksová locality is given in Table 1.

The PRP series consists of 12 partial plots, each of 0.09 ha in size. Three geometric (schematic) interventions were applied to four plots at first, followed by selective tending. On another four plots, only selective interventions were performed – free crown thinning according to Štefančík (1984a, 1984b). Four partial plots remained without interventions (control plots). Partial plots had different spacing (labels A, B, C, D) or the initial number of trees, which are observed in three replications and also represent three management methods. In the lower row, plots A_1, B_1, C_1 and D_1 were managed by schematic thinning (the first three interventions, then selectively) from the beginning. Pruning (removing branches) was performed on the half of the D_1 plot during the 1st measurement (before the intervention) in 1990, while the other half was left without this intervention. In the middle row, plots A_2, B_2, C_2 and D_2 remained without intervention as they were intended as control plots. In the upper row, in plots A_3, B_3, C_3 and D_3 selective thinning was used. A draft of the PRP with individual spacing variants and replications is shown in Figure 1.

From the establishment of the PRP to 1990, i.e. the stand age of 20 years, no interventions were carried out. Later, three thinnings were carried out (1990, 1996 and 2000) together with biometric measurements (Štefančík, Štefančík 2002). At the turn of 2002/2003, the plots were affected by the 1st snow storm, when many trees were damaged or removed, so that the stand remained without intervention until the subsequent 4th biometric measurement in 2005. However, the snow storm occurred later again (2008), so that no intentional intervention was carried out in the stand even at the 5th biometric measurement in 2010. After the disaster in 2008, a lot of stems were damaged by ungulate game due to fencing destruction. The last intervention was carried out in 2015 (stand age of 45). The initial principles were a little modified, i.e. predominantly the health selection has been applied as a result of previous damage to trees by ungulate game and crown breaks due to snow over the last 10 years. Between 2016 and 2018, most partial plots were affected repeatedly by two snow storms and rime. Among the silvicultural practices, two methods were applied to plots with selective tending, i.e. the method of promising trees (up to the age of 40) and the method of target trees. A geometric intervention (each second row was removed by the first intervention, followed by removing each sixth row of the intervention and finally each second row) was applied to four plots for the first three measurements and then a selective one (Figure 1).

Table 1. Basic characteristics of a series of permanent research plots (PRP) at the Biely Váh – Luksová locality

Characteristic	Biely Váh - Luksová PRP
Establishment of PRP	1972
Age of stand (years)	20 (in 1990)
Site index	32
Geomorphologic unit	Kozie Chrbty
Aspect	North
Altitude (m)	1 100
Slope (in percentage)	14
Parent rock	limestones, dolomites
Soil unit	Rendzina on the slope deposit of limestones and dolomites
Forest altitudinal zone	6th spruce-beech-fir
Ecological rank	B (Fertile mesophilous)
Management complex of forest types	611 – fertile fir-beech spruce forests
Forest type group	*Abieto-Fagetum* (AF) higher tier
Forest type	6302 nitrifying low-herbaceous fir beech forests (higher tier)
Average annual temperature (°C)	5.0
Sum of average annual precipitation (mm·year^{-1})	1 140

The diameter at breast height of all numbered trees was measured to the nearest 1 mm at two mutually perpendicular directions. In the field work, in addition to quantitative features ($d_{1.3}$ − diameter at breast height, tree height to the nearest 1 mm, crown radii in horizontal projection to the nearest 0.1 m), trees were also evaluated by their silvicultural and economic classification (Štefančík, Bošeľa 2014), focusing on the silviculture of selective quality trees (target and promising trees).

Data were processed by standard methods used in research on silviculture-production relations in stands with thinnings (Štefančík 1984). The slenderness quotient was calculated from 100 thickest trees per hectare as the $h/d_{1.3}$ ratio (Slodičák, Novák 2007). The merchantable volume was cal-

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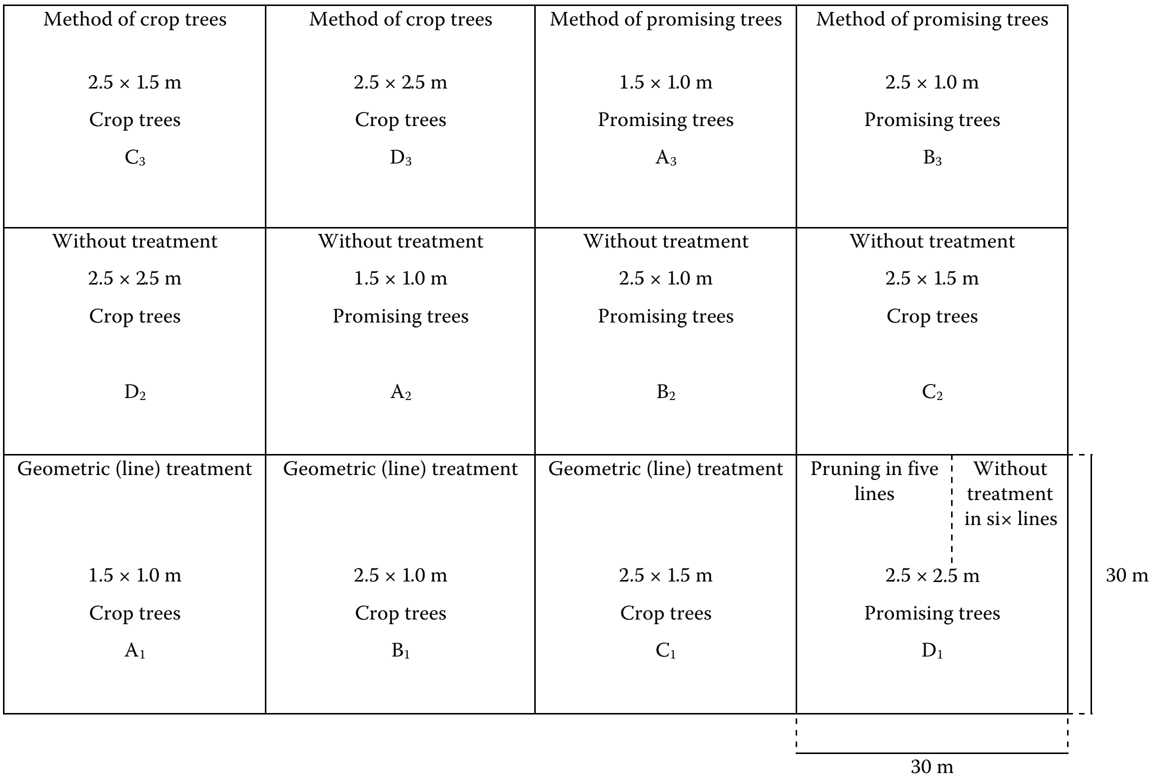

Fig. 1. Scheme of the series of the Biely Váh – Luksová PRP including the methods of their tending (A, B, C, D – alternatives of spacing, index 1, 2, 3 – replication of spacing and/or plot lines)

culated by volume equations (Petráš, Pajtík 1991). Excel and QC Expert programs, Version 3.3 (Kupka 2013) or ANOVA for determination of statistical significance of differences were used to calculate the basic statistical characteristics.

RESULTS AND DISCUSSION

Stand structure

The development of the percentage of trees that create the crown stand level and/or main canopy trees (1^{st} + 2^{nd} Kraft's tree class) at the beginning of research and after 20 or 30 years of observation is shown Figure 2. At the beginning, the proportion of the crown stand level was more or less balanced. On average, it ranged from 64 to 71% for individual spacings (A, B, C, D). After 30 years, the share of the above-mentioned level increased on 2/3 of plots, or at 70 to 83% on average for individual spacings, maximally on plots A_1, B_1, C_2, D_3 and minimally on plots A_2, C_3.

However, different values between partial plots pointed to an ambiguous dependence on the initial spacing and the method of tending. However, according to the average values for the investigated spacings, two denser spacings (A, B) had a lower proportion of the crown stand level in comparison with the sparser ones (C and D). It should be noted that the stands were markedly affected by repeated snow storms and rime, which disrupted the development (height shifts) in both tended and control plots in particular over the last 10 years. In the first 20 years of research, snow storms affected mainly thinner individuals of the lower tree classes, which was also found by other authors (e.g. Pařez 1972; Braastad 1979; Slodičák 1983). However, over the last 5 years, the stand has mainly been damaged by rime, which mostly damages height predominant trees with large crowns (Stolina et al. 1985). This also caused different damage to plots, depending on the initial spacing and management method.

Static stability

Tending interventions in young Norway spruce stands are aimed primarily at ensuring favourable static stability (Pařez 1972; Slodičák 1983; Chroust

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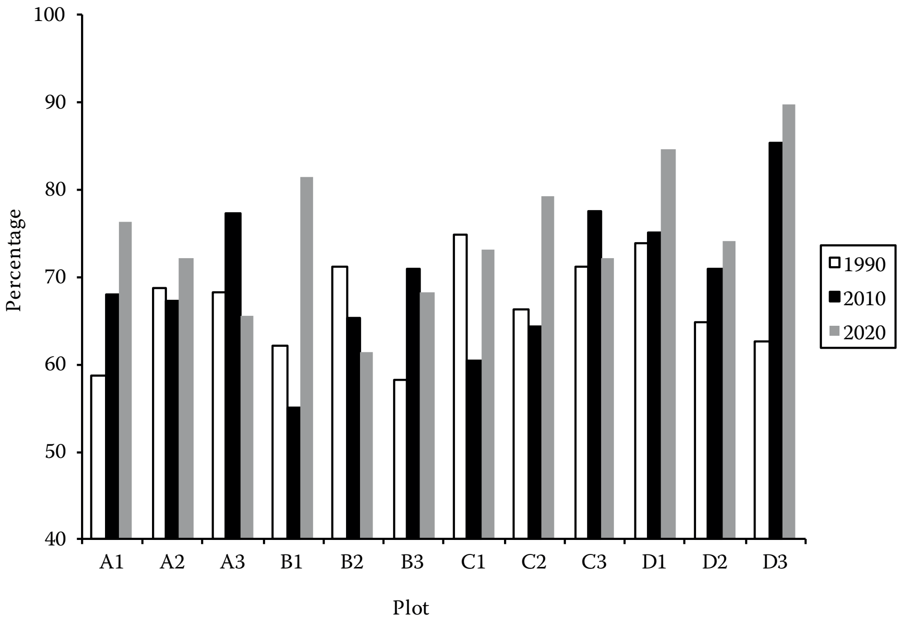

Fig. 2. Proportion of the crown stand level (1st + 2nd tree class) during the period of investigation

1997; Slodičák, Novák 2007), which can be most influenced by appropriate tending up to the age of 25–30 years (Mráček, Pařez 1986; Slodičák 1987; Slodičák, Novák 2006, 2007; Slodičák et al. 2010; Štefančík, Kamenský 2011). The slenderness quotient values serve as significant indicators of this static stability (Figure 3).

At the beginning of research, these values were relatively equal on all plots (from 0.83 to 0.95) (Štefančík 2013). Comparison of the slenderness quotient values over the last 10 years showed an improvement, except for the plot with the first three geometric interventions (plot A_1 at the original 1.5 × 1.0 m spacing). After 30 years of observation, the highest values were observed on the plots with the densest initial spacing (1.5 × 1.0 m). The differences from the other plots (spacings) were also statistically significant (for $\alpha = 0.05$). For all other spacings, the differences between the plots were minimal and statistically insignificant ($P > 0.05$). The same finding was published by Nilsson (1994), who found for nearly identical four spacings like in our experiment that the height/diameter ratio was not influenced by spacing. For management in the densest stands (spacings 1.5 × 1.0 m; 2.5 × 1.0 m), the most favourable values were found for selective tending. On the contrary, with the sparser stands (spacings 2.5 × 1.5 m;

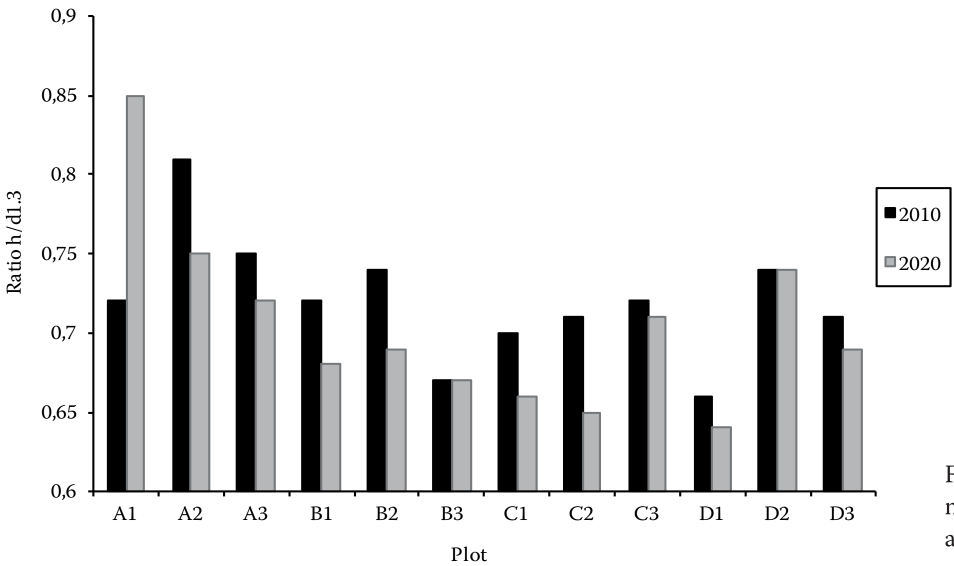

Fig. 3. The values of slenderness quotient for the last decade of investigation

https://doi.org/10.17221/18/2020-JFS

2.5 × 2.5 m), the values were more favourable on the plots with the first three geometric interventions.

Higher values compared to those found on the Biely Váh – Luksová PRP were given by Piskun (1984) for the PRP Turzovka – Semetéš, but at the stand age of 11 years. The slenderness quotient values ranged from 1.04 to 1.16, increasing with increasing stand density. This trend was also noted by Nilsson (1994) in a 30-years-old Norway spruce stand with four spacing variants (from 1.0 × 1.0 m to 2.5 × 2.5 m), but differences were not statistically significant.

Kamenský, Štefančík (1990) reported the same findings in the 20-year Norway spruce stand on the Turzovka – Semetéš PRP, which had the same spacings and variants of the research programme like the Biely Váh – Luksová PRP. The positive effect of geometric intervention and combined (geometric + selective) intervention on the stability of Norway spruce stand (at small-pole stage) with respect to snow damage was also revealed by Saniga (1996). He found at the initial 2 × 1 m spacing that combined (mixed thinning) and geometric thinning with 33% intervention intensity had the positive effect on the Norway spruce stand stability (at small-pole stage) from the snow damage aspect. Similarly, Burschel (1981) observed an improvement in the static stability of the stand and a decrease in the risk of snow damage at less than 2 000 trees per hectare at the upper height of 15 to 20 m. Burschel et al. (1974), Konôpka (1992), Poleno, Vacek et al. (2009) also obtained favourable results for static stability by the target tree method.

Regarding the method of tending, we found out the lowest values at the selective tending of the two densest stands. Small differences between control plots and plots with combined (schematic + selective) tending were found at these spacings: 2.5 × 1.0 m or 2.5 × 1.5 m.

Table 2. Changes in the number of trees on Biely Váh – Luksová PRP

Plot	Spacing (m)	Initial stage in 1972 (trees·ha⁻¹)	Decrease from 1972 to 1990 (trees·ha⁻¹)	Decrease from 1972 to 1990 (%)	Number of trees per hectare before the first treatment (trees·ha⁻¹)
A_1	1.5 × 1.0	6 667	2 156	32.3	4 511
A_2			2 078	31.2	4 589
A_3			1 956	29.3	4 711
$\overline{A}$			2 063	30.9	4 604
B_1	2.5 × 1.0	4 000	1 067	26.7	2 933
B_2			1 078	27.0	2 922
B_3			1 478	37.0	2 522
$\overline{B}$			1 208	30.2	2 792
C_1	2.5 × 1.5	2 667	500	18.7	2 167
C_2			823	30.9	1 844
C_3			700	26.2	1 967
$\overline{C}$			674	25.3	1 993
D_1	2.5 × 2.5	1 600	322	20.1	1 278
D_2			333	20.8	1 267
D_3			322	20.1	1 278
$\overline{D}$			326	20.4	1 274

A, B, C, D – alternatives of spacing, index 1, 2, 3 – replication of spacing and/or plot lines (for detailed explanation see Figure 1)

Quantitative production

Table 2 shows a decrease in the number of trees over 18 years, i.e. from the initial state (establishment of the PRP) to the start of observations of tending. It can be seen that during this period, the decrease was similar within the spacing variants, namely in the densest A variant (average 30.9%) and in the sparsest D variant (average 20.4%). In the other two spacing variants (B and C), the decrease of individuals showed much greater variability. The largest decrease of trees was registered in the plots with the smallest spacing, or it decreased with decreasing stand density. The difference between the densest and the sparsest plot was 10.5% on average. It is known that during the artificial regeneration of Norway spruce, the greatest decrease occurs in the first year, or in the next 2–3 years after planting. These losses vary from 10 to 12% (Piskun 1984) on annual average and somewhere more (16–17%) (Mráček, Pařez 1986). From this point of view, the decrease of trees over 18 years on the above-mentioned PRP series can be assessed as relatively low, but this could also be due to the replanting of young plantations for example, as we have no information about it.

The description of mensurational variables on plots at 50 years of age is shown in Table 3. In plots with the original three geometric interventions (A_1, B_1, C_1, D_1), after 30 years there was a minimum number of trees on the plot with the initial spacing of 2.5 × 1.0 m (178 trees per 1 ha) and a maximum number of trees remained on the plot with the densest initial spacing of 1.5 × 1.0 m (567 trees·ha⁻¹). On

https://doi.org/10.17221/18/2020-JFS

Table 3. Mensurational characteristics on Biely Váh – Luksová PRP at the age of 50 years

Plot	Initial spacing (m)	Number of trees (trees·ha^{-1})	Basal area (m^2·ha^{-1})	Merchantable volume (m^2·ha^{-1})	Mean diameter (cm)	Mean height (m)
A_1	1.5 × 1.0	567	38.2	420	29.3	22.7
A_2		400	22.8	245	27.0	21.8
A_3		356	18.6	193	25.8	21.1
B_1	2.5 × 1.0	178	15.9	182	33.7	24.1
B_2		344	19.5	210	26.9	21.8
B_3		456	28.0	297	28.0	21.9
C_1	2.5 × 1.5	289	22.8	258	31.7	23.5
C_2		478	29.4	321	28.0	22.2
C_3		600	34.7	365	27.1	21.6
D_1	2.5 × 2.5	289	24.9	282	33.1	23.9
D_2		600	33.0	349	26.5	21.6
D_3		322	18.8	197	27.3	21.7

A, B, C, D – alternatives of spacing, index 1. 2. 3 – replication of spacing and/or plot lines (for detailed explanation see Figure 1)

the plot with the sparsest spacing (D_1), at the first measurement (at the age of 20 years), the small-pole stage stand was not closed yet, and not even at the second measurement, i.e. at the age of 26 years, and thus the intervention was not necessary. On the other three plots with geometric interventions, the intensity of intervention (thinning of living trees) by basal area varied depending on the original spacing (stand density) and the order of intervention. In the 1st thinning, the strongest intervention was carried out on plot B_1 (50.3%) and the weakest on C_1 (34.4%). The second intervention was the strongest on plot A_1 (38.3%) and the weakest on plot C_1 again (28.6%). The 3rd intervention was strongest on plots B_1 and D_1 (49.4% and 47.0%), or the weakest on plots A_1 and C_1 (10.5% and 15.7%) (Štefančík, Štefančík 2002). Different intensity of interventions on plots with geometric thinning was due to different number of rows removed for each intervention. Chroust (1988) reported the number of trees (N) 1,839 inds·ha^{-1}, basal area (G) 36,9 m^2·ha^{-1} and growing stock 288 m^3·ha^{-1} on the plot with geometric intervention (50% intensity) at the age of 30 years (1.6 × 1.6 m spacing). Values found for this age on the Biely Váh – Luksová PRP (the plot with 1.5 × 1.0 m spacing) were lower: N 1,167 trees·ha^{-1}, G 19.2 m^2·ha^{-1} and V 122 m^3·ha^{-1}, which was caused by more intense intervention (77%) or three thinnings performed compared to Chroust's (1988) data. Only one thinning was carried out (intensity from 2.6 to 5.7%) in the Biely Váh − Luksová PRP during the next 20 years (stand age of 30 to 50 years). This was due to the fact that in this period the stands were affected by several snow storms or rime. This caused a decrease of the basal area (from 18.1% to 47.7%) on plots with geometric interventions in the above-mentioned period.

N ranged from 344 to 600 trees·ha^{-1} on control plots. Before the stand was damaged by snow breakages (the first three measurements), the largest decrease of trees on control plots was caused by self-thinning, and at all three measurements the decrease tended to increase with a decreasing spacing. The percentage of decrease by G ranged from 0.6 to 6.0% (Štefančík, Štefančík 2002). Later, however, due to the first snow storm, the control plots (without tending) were most affected, when at the age of 35 years another decrease was 3.3 to 25.0% of the basal area, whereas on plots with selective tending it was less (2 to 11.7 %), or in plots with schematic interventions 1.8 to 12.1%. The same trend was confirmed for the 2nd snow storm at the age of 40 years, showing that in almost all cases snow damage decreased with the increasing initial spacing, with the lowest damage in plots with selective tending and highest in control plots (regardless of the initial spacing). However, in the last snow storm and rime damage at the age of 48 years, the plots with selective tending were affected to the largest extent. This was due to the fact that rime increasingly affects the tallest trees with large crowns (Stolina et al. 1985). This is the case on plots with selective tending, where the tallest and thickest (target) trees are intentionally grown and released by thinnings. A second fact is that the disaster occurred in the same year after the intervention, which generally increases the risk of snow and rime damage, especially in Norway spruce stands

https://doi.org/10.17221/18/2020-JFS

Table 4. The total decrease of trees over 30 years

Plot	Thinning and other decrease						Dead trees (self-thinning)					
	N		G		V_{7b}		N		G		V_{7b}	
	(trees·ha^{-1})	% of TP	(m^2·ha^{-1})	% of TP	(m^3·ha^{-1})	% of TP	(trees·ha^{-1})	% of TP	(m^2·ha^{-1})	% of TP	(m^3·ha^{-1})	% of TP
A_1	3 600	79.8	24.3	38.0	117	21.6	344	7.6	1.4	2.2	6	1.2
A_2	2 166	47.2	30.5	48.7	285	48.7	2 023	44.1	9.4	14.9	55	9.4
A_3	3 044	64.6	30.1	52.8	192	43.5	1 311	27.8	8.3	14.6	57	12.9
B_1	2 656	90.5	26.1	58.6	141	40.6	99	3.4	2.5	5.7	25	7.2
B_2	1 767	60.5	27.9	53.6	220	48.0	822	28.1	4.6	8.8	29	6.3
B_3	1 633	64.7	20.2	38.6	153	31.9	433	17.2	4.1	7.8	29	6.1
C_1	1 711	79.0	26.5	52.0	192	41.7	167	7.7	1.6	3.2	10	2.2
C_2	1 022	53.8	15.0	31.9	114	25.7	399	21.0	2.6	5.5	8	1.7
C_3	1 123	57.1	18.2	31.1	138	24.9	254	12.9	5.5	9.5	52	9.4
D_1	911	71.3	18.2	41.6	130	31.2	89	7.0	0.7	1.6	5	1.1
D_2	521	41.2	13.7	28.1	125	25.5	145	11.4	1.9	3.9	14	2.9
D_3	721	56.4	19.3	44.5	173	41.4	234	18.3	5.2	12.0	47	11.3

N – number of trees; G – basal area; V_{7b} – merchantable volume; TP - total production of respective stand parameters; A, B, C, D – alternatives of spacing, index 1. 2. 3 – replication of spacing and/or plot lines (for detailed explanation see Figure 1)

of middle age at altitudes from 900 to 1 100 m a.s.l. (Stolina et al. 1985).

As for the plots with selective tending, after four interventions and three snow storms, most trees (Table 3) remained on plot C_3, i.e. with the initial spacing of 2.5 × 1.5 m (600 inds·ha^{-1}), and on plot B_3 with its initial spacing of 2.5 × 1.0 m (456 inds·ha^{-1}). These numbers of individuals are markedly lower due to disasters in the past compared to plots under similar natural conditions and tending method (Chroust 1997; Slodičák, Novák 2007).

The most comprehensive information on the total quantitative development of the investigated stands is provided by the analysis of total production and total decrease of trees over the 30-year period (Tables 4 and 5). In the basal area, the largest decrease was due to thinning and other decrease (breaks, windfalls) in plots with the initial spacing of 2.5 × 1.0 m (50.3% of

Table 5. Development of quantitative production of the stand on the Biely Váh – Luksová PRP

Plot	Age (years)	Total decrease						Total production				
		N		G		V_{7b}		N	G		V_{7b}	
		(trees·ha^{-1})	% of TP	(m^2·ha^{-1})	% of TP	(m^3·ha^{-1})	% of TP	(trees·ha^{-1})	(m^2·ha^{-1})	ITS	(m^3·ha^{-1})	ITS
A_1	20–50	3 944	87.4	25.7	40.2	124	22.8	4 511	63.8	4.496	544	23.850
A_2	20–50	4 189	91.3	39.9	63.6	340	58.1	4 589	62.7	3.900	585	22.912
A_3	20–50	4 355	92.4	38.4	67.4	249	56.4	4 711	57.0	4.774	443	41.935
B_1	20–50	2 755	93.9	28.6	64.3	167	47.8	2 933	44.5	3.526	349	11.967
B_2	20–50	2 589	88.6	32.4	62.4	249	54.3	2 922	52.0	4.816	459	23.845
B_3	20–50	2 066	81.9	24.3	46.4	182	38.0	2 522	52.3	7.455	480	52.645
C_1	20–50	1 878	86.7	28.1	55.2	202	43.9	2 167	50.9	4.947	460	17.899
C_2	20–50	1 421	74.8	17.6	37.4	121	27.4	1 900	47.1	8.991	442	59.930
C_3	20–50	1 377	70.0	23.7	40.6	190	34.3	1 967	58.4	10.536	555	82.436
D_1	20–50	1 000	78.3	18.9	43.2	135	32.3	1 278	43.8	8.247	417	34.791
D_2	20–50	666	52.6	15.5	32.0	139	28.4	1 267	48.6	10.822	488	61.053
D_3	20–50	955	74.7	24.5	56.5	220	52.7	1 278	43.3	10.984	418	69.223

N – number of trees; G – basal area; V_{7b} – merchantable volume; TP – total production of respective stand parameters; ITS – Index of total stand; A, B, C, D – alternatives of spacing, index 1. 2. 3 – replication of spacing and/or plot lines (for detailed explanation see Figure 1)

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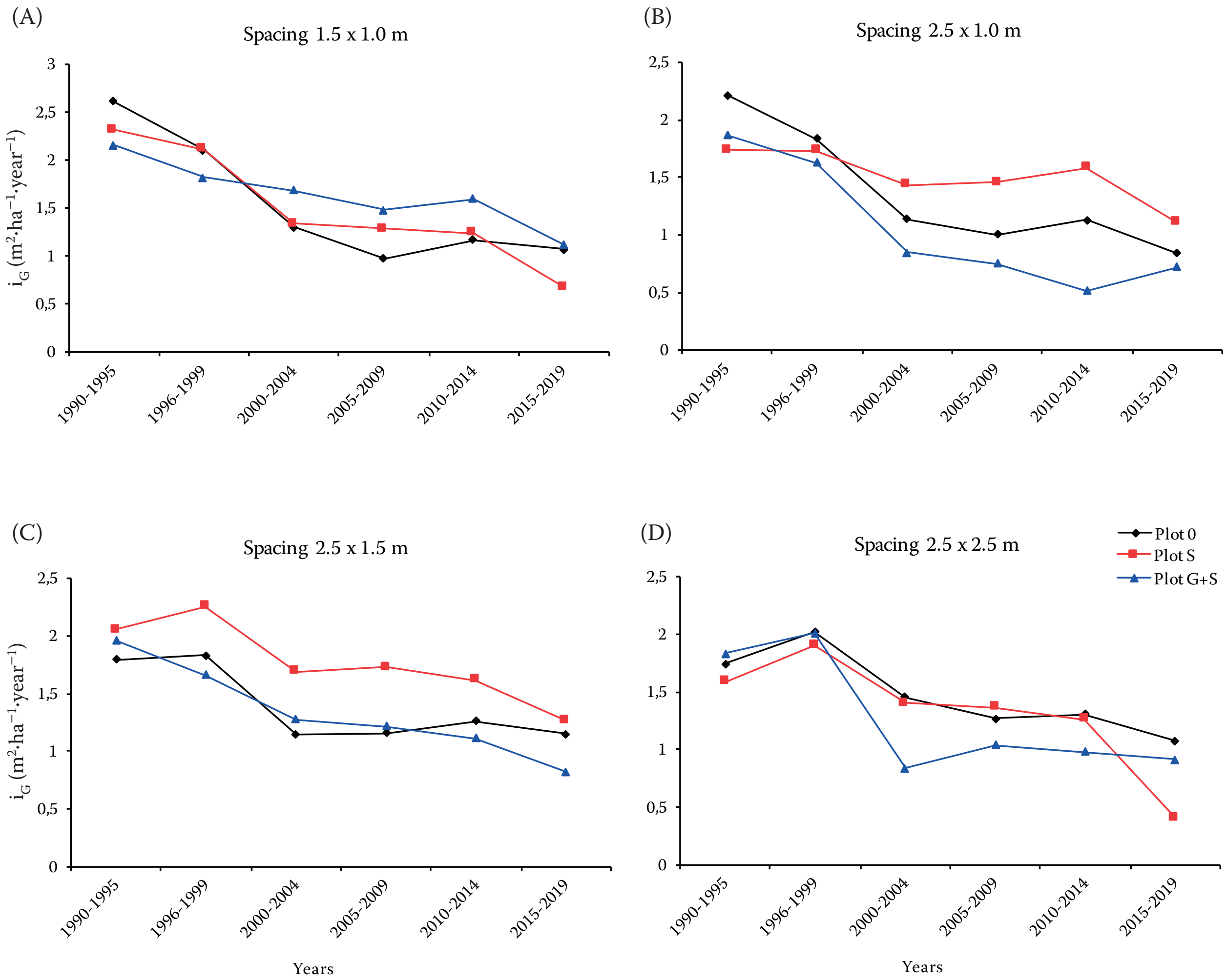

Fig. 4. Current annual basal area increment (i_G) according to the initial spacing (the plots with the same spacing were grouped), 0 – plots with no treatment; S – plots with selective thinning; G+S – plots with geometric (the first 3 interventions) and selective thinning)

total production on average) or 1.5 × 1.0 m (46.5% of total production). The same trend was also found in self-thinning and total decrease. Plots with the densest original spacing had the highest decrease.

When comparing the total decrease (Table 5) according to management methods, we found the largest decrease (by G) in plots with selective tending and the lowest in control plots. However, the difference was negligible (3.9% on average). On control and selectively managed plots, the total decrease was smaller with increasing spacing.

Evaluation of the total production by basal area and merchantable volume using the index of total stand, which expresses the basal area increment (merchantable volume) for the whole observed period, clearly showed the best results for selective tending. The highest values were found for the sparsest spacings, i.e. 2.5 × 1.5 m and 2.5 × 2.5 m. More or less, this also confirms the course of the current annual increment of the basal area in relation to individual spacings (Figure 4). Braastad (1979) also found a strong correlation between spacing and total production in a 28-years-old Norway spruce stand. In the plot with 3.0 × 3.0 m spacing, the total production was only 52.6% compared to the plot with 1.2 × 1.2 m spacing. On the Biely Váh – Luksová PRP it was 84%, but at the stand age of 50 years.

These results indicate that a decrease in production occurs at the schematic tending (geometric interventions) in the small-pole growth stage in comparison with selective tending. Mráček, Pařez (1986) were

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convinced that geometric interventions are suitable mainly in very young stands (in the period of cleanings) and are particularly important in very dense thickets. For wider spacings (2–3 × 1 m), according to these authors, geometric intervention is not recommended and these authors consider the spacing of 1.5 × 1.5 m as a marginal spacing. Concerning the total volume production (TVP), Mráček, Pařez (1986) stated that stands established at a sparse spacing initially showed a considerable predominance in both the merchantable volume and the TVP in comparison with denser spacings. Later, these differences disappeared. The above-mentioned authors presented the results of German researchers (Vanselow, Kramer, Busse, and Jaehn) who found that TVP at the age of 48 years was 29 to 40% lower at extremely wide spacings (4 × 4 m, i.e. 625 individuals per 1 ha) compared to TVP at narrow (1.2-1.3 m) and medium dense (1.8 to 2.0 m) square spacings. A similar dependence was confirmed on the Biely Váh − Luksová PRP, when the

Table 6. Development of the basic characteristics of promising and target (crop) trees

Plot	Type of treatment (category of trees)	Age (years)	Number of trees		Basal area		Merchantable volume	
			(trees·ha^{-1})	(% out of the main stand)	(m^2·ha^{-1})	(% out of the main stand)	(m^3·ha^{-1})	(% out of the main stand)
A_1	geometric (target)	30	278	26.9	6.96	40.5	48.55	44.2
		40	233	37.5	12.64	47.0	120.48	48.9
		50	178	31.4	14.99	39.3	168.34	40.1
A_2	without tending (promising) (target)	30	578	18.0	11.50	31.5	71.70	35.6
		40	189	32.7	8.06	46.6	74.62	49.1
		50	122	30.5	9.03	39.5	99.06	40.4
A_3	selective (promising) (target)	30	667	29.1	11.40	49.8	68.99	56.4
		40	333	45.4	11.86	54.9	104.00	56.6
		50	89	25.0	6.98	37.5	76.77	39.7
B_1	geometric (target)	30	189	42.6	5.16	56.5	35.94	59.5
		40	89	40.1	6.14	49.5	60.66	51.1
		50	44	24.7	5.04	31.7	59.17	32.5
B_2	without tending (promising) (target)	30	733	31.7	14.13	47.8	87.33	52.1
		40	144	28.2	6.18	36.9	57.04	38.4
		50	44	12.8	4.32	22.1	49.68	23.7
B_3	selective (promising) (target)	30	444	29.0	9.09	45.6	57.11	49.6
		40	222	32.2	10.82	43.1	99.06	44.7
		50	133	29.2	12.12	43.3	134.01	45.0
C_1	geometric (target)	30	289	35.2	7.64	46.6	54.07	49.8
		40	178	42.2	10.91	55.1	106.03	58.0
		50	111	38.4	11.59	50.9	135.70	52.5
C_2	without tending (target)	30	267	15.2	5.17	22.9	32.48	25.3
		40	133	28.5	6.63	38.6	63.02	40.3
		50	89	18.6	8.90	30.2	103.63	32.3
C_3	selective (target)	30	322	21.8	7.40	32.4	46.90	34.7
		40	289	32.5	13.08	40.3	118.38	41.3
		50	133	22.2	9.37	27.0	101.02	27.7
D_1	geometric (promising) (target)	30	544	81.7	12.00	93.3	81.46	95.5
		40	200	64.3	12.48	79.0	121.01	80.9
		50	178	61.6	18.51	74.4	214.37	75.9
D_2	without tending (target)	30	278	22.7	7.13	31.2	45.64	32.5
		40	233	30.4	10.58	37.9	99.6	39.2
		50	133	22.2	9.69	29.3	106.69	30.6
D_3	selective (target)	30	422	36.9	9.28	48.4	58.68	50.5
		40	356	47.1	15.32	56.2	138.80	57.7
		50	144	44.7	9.20	48.9	96.58	48.9

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TVP of the densest spacing (1.5 × 1.0 m) exceeded the values from other spacings. Nilsson (1994) stated that the major limiting factor for growth at dense spacings was not light but mineral nutrients and/or water.

Qualitative production

Table 6 shows the basic mensurational characteristics of the target (promising) trees, which represent the quality of production in production forests and on which the forester focuses above all and/or are of particular importance for the static stability of the stand. At the age of 30 years, before snow damage, the highest number of promising trees was in the plot without any intervention, i.e. B_2 (733 trees·ha^{-1}), and the lowest on the plot with selective tending, i.e. B_3 (444 trees·ha^{-1}). As for the target trees of this age, the highest number of trees was on the plot with selective tending, i.e. D_3 (422 trees·ha^{-1}), and the lowest on the plot with schematic thinning, i.e. B_1 (189 trees·ha^{-1}).

During further stand development, damage of the stand by snow breakages and rime also affected promising or target trees, but with different intensity. In plots managed first by the promising tree method (later target trees), the highest decrease was recorded in control plots A_2 and B_2, where 21.1% and 6.0% of the original number of promising trees remained, and also in plot A_3 where 13.3 % of trees remained. These plots were established at the densest spacing, i.e. 1.5 × 1.0 m or 2.5 × 1.0 m. On the contrary, plots B_3 and D_1, which were established at a spacing of 2.5 × 1.0 m or 2.5 × 2.5 m, were least affected in this respect. Approximately 1/3 of the original number of promising trees remained on these plots even after the above-mentioned disasters.

In plots managed by the method of target trees from the beginning, the highest decrease was on the plot with schematic interventions, i.e. B_1 with a spacing of 2.5 × 1.0 m, where only 23.3% of target trees remained. The number of target trees was least reduced by snow storm in the plot with the original three geometric interventions and later selective tending, i.e. A_1 (spacing of 1.5 × 1.0 m), where 64.0% of the original number of target trees remained.

The proportion of promising (target) trees from the main stand is considered as an important indicator of the stand quality. Expressed by the number of these trees, the best results were found in plots D_1 (61.6%) and D_3 (44.7%), i.e. in plots with the sparsest spacing (2.5 × 2.5 m), managed by initially schematic and later selective interventions. The same trend was also shown in basal area and merchantable volume. Similar results were reported by Prokopjev (1983), who found the best results for production in terms of quality at the initial spacing of 3.0 m × 1.5 m (2 200 trees·ha^{-1}).

The data of Table 6 shows that the number of target trees at the age of 50 years ranges from 44 trees·ha^{-1} to 178 trees·ha^{-1}. At the age of 40 years, the highest number of target trees at all four spacings was

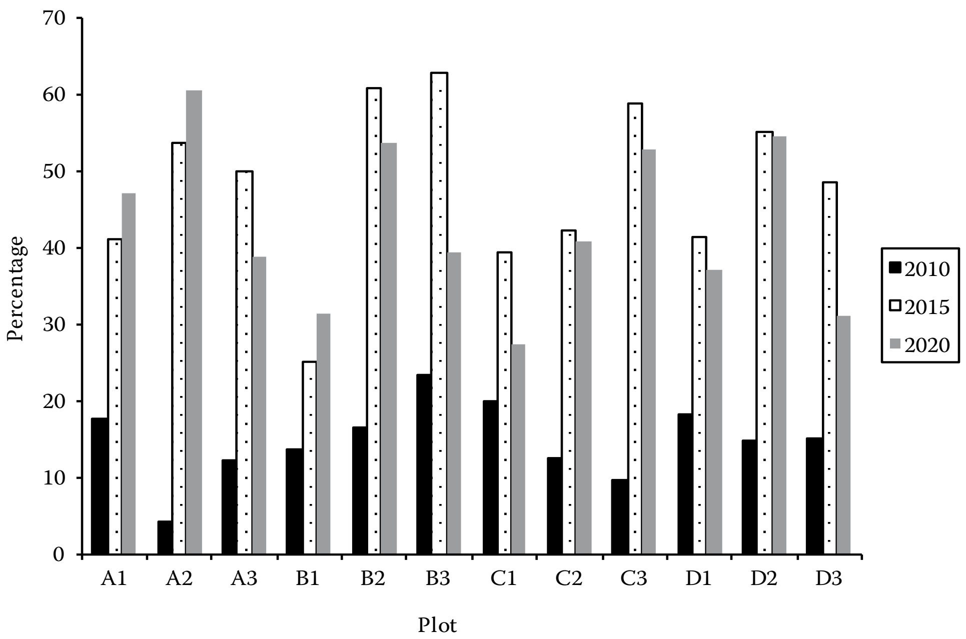

Fig. 5. Proportion of stem damage by ungulate game during last decade

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on plots with selective tending and the lowest on plots with schematic thinnings and on control plots (without tending). However, at present, the number of target trees in the stand can be considered insufficient in view of its further development, in comparison with the results of other authors (Abetz 1979; Štefančík 1986; Schober 1990; Spellmann, Nagel 1996; Štefančík, Štefančík 2000; Slodičák, Novák 2007). These authors recommend 300 to 400 target trees as a sufficient number for Norway spruce stands. No plot currently meets this criterion. A lower number of target trees than 400 individuals per hectare was also found by Slodičák, Novák (2007), who reported only 360 to 380 target trees per ha on the IUFRO experimental series of plots CZ – Vítkov 13.

Damage by ungulate game

As a result of the fencing destruction on the whole PRP, extensive damage to trees was caused by bark stripping. This was particularly evident over the last 10 years, when the percentage of stem damage has increased markedly (Figure 5) compared to the first smaller damage to the fence. While in 2010 the damage caused by ungulate game ranged from 4.3% to 23.3%, in 2015 it was from 25.0% to 62.9%, or 27.3% to 60.5% in 2020. In 2015 we found the worst damage on the plot with selective tending (55.1% on average). Damaged trees, with different intensity of stripping, were affected by stem breaks to a greater extent. This was also the reason for the highest decrease of trees in this management method, which corresponds to data in Table 5. Ungulate game damaged mainly the thickest individuals or a considerable part of target trees. This is the reason for their low (insufficient) number in comparison with conventional models (Slodičák, Novák 2007a).

CONCLUSION

The development of the stand was influenced by several snow storms and rime events, which together with the damage caused by ungulate game manifested itself markedly in the total decrease of individuals and low (insufficient) number of target trees.

According to the average values for each spacing, two denser spacings (A, B) had a lower proportion of the crown stand level compared to the sparser spacings (C and D). As for the static stability, the lowest stability but the highest values of h/d ratio were found for selective tending of the two densest spacings. Small differences between control plots and plots with combined (schematic + selective) tending were found at these spacings: 2.5 × 1.0 m, or 2.5 × 1.5 m.

Data evaluation of the total production by basal area and merchantable volume using the index of total stand, which expresses the basal area increment (merchantable volume) for the whole observed period, showed clearly the best results for selective tending.

Based on a detailed analysis of the silviculture-production relationships in terms of quantitative production in a 50-year Norway spruce stand on plots with different initial spacing and over 30 years of observation (after four thinning interventions + three snow storm and rime events), it can be concluded that for the given conditions of mountain Norway spruce stands (an altitude of 1 100 m a.s.l.), the sparsest density (spacings, i.e. 2.5 × 1.5 and 2.5 × 2.5 m), proved to be the best. These results correspond to data according to Slovak Technical Standard 48 2210 from 2013 "Silviculture. Reforestation and Care of Forest Plantations and Young Stands". For natural conditions corresponding to the Biely Váh – Luksová PRP, the minimum normative number of seedlings is 2 000 individuals per hectare, or 2.2 × 2.2 m spacing.

Based on the above-mentioned results of experiment the method of selective tending should be recommended also for stands with high game pressure on the assumption that consistent stem protection especially of target (crop) trees is carried out.

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