Growth characteristics of oak (*Quercus petraea* [Mattusch.] Liebl.) stand under different thinning regimes

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ABSTRACT: In the paper, selected quantitative characteristics of 57-year-old oak pole stage stand were analysed on plots with different thinning regimes at its establishment. Six thinning treatments were performed in an interval of 8, 14 and/or 5 years. We applied the method of target (crop) trees on three partial plots and method of promising trees on one plot with different intensity of releasing the trees of selective quality (promising and target trees). The results of both methods were compared with the control (untreated plots). Preliminary outcomes suggested that from the quantitative aspects the best results were obtained on plots where target trees were released by removing one and/or two trees at the stand age of 19 years. These results confirmed the well-known fact that the tending of young oak stands should be realized by thinnings of intermediate intensity.

Keywords: oak; *Quercus petraea* (Mattusch.) Liebl.; thinning; promising trees; target trees

Oak is the second most widespread tree species of hardwood trees in Slovak forests and takes up 13.3% of the total forest area (Green report 2009). Although in unmixed and mixed oak stands an emphasis was especially laid on quantitative production (e.g. Krahl-Urban 1959; Venet 1967; Baksa 1970; Korpeľ 1981), the main goal is to support the high quality of production (e.g. Korpeľ 1964; Schütz 1993; Chroust 2007; Slodičák et al. 2009). This can be achieved by suitable tending methods, performed especially in young growth phases (Vyskot 1958; Hochbichler 1993; Chroust 1997; Korpeľ 1981). Consequently, a lot of experiments were done in the past that were aimed at a comparison of the effects of various thinning methods applied in oak stands (Chroust 1958, 1997; Korpeľ 1964, 1981; Assmann 1968; Utschig, Pretzsch 2001, etc.). It can be concluded from the above-mentioned experiments that positive crown thinning with a certain amount of the best-quality (valuable, target) trees released by proper thinning intensity is considered as a suitable regime for management of oak stands. From this viewpoint, the method of promising and/or target trees also seems to be very effective for oak stands. Using this method, the attention is focused on the tending of selected (target) trees whose number ranges from 70 to 250 individuals per hectare (Baksa 1970; Roy 1975; Dong et al. 1997; Chroust 2007; Slodičák et al. 2009). The crucial problem is correct selection and marking of a sufficient number of the above-mentioned trees of selective quality (promising or target trees). A production goal can differ from country to country. However, under the conditions of Slovak Republic in oak stands, it is optimal to achieve and/or to tend from 100 to 200 target trees·ha^{-1} at rotation of 140–180 years, while the mean spacing of target trees should be 7–10 m (Korpeľ 1984).

Subsequently, the aim of this paper is to compare changes in selected stand characteristics in oak stands managed by different thinning regimes for almost 40 years. Special attention was paid to the development of trees of selective quality released by different intensity.

MATERIAL AND METHODS

The object of investigation was a sessile oak (*Quercus petraea* [Mattusch.] Liebl.) pole stage stand on the series of permanent research plots

Table 1. Tree species composition according to basal area on Veľká Stráž II PRP

Plot	Age (years)	Tree species (%)					
		oak	hornbeam	aspen	larch	fir	spruce
P 1	42	96.3	1.5	1.4	0.8	–	–
	57	95.6	3.2	–	1.2	–	–
P 2	42	96.8	2.1	0.5	0.6	–	–
	57	97.2	2.8	–	–	–	–
P 3	42	98.1	1.2	0.7	–	–	–
	57	96.5	3.5	–	–	–	–
N	42	95.2	4.7	–	–	0.1	–
	57	90.2	9.7	–	–	0.1	–
0_C	42	98.8	1.2	–	–	–	–
	57	97.5	2.5	–	–	–	–
0_N	42	95.6	1.9	1.1	1.3	–	0.1
	57	93.8	2.9	1.4	1.6	–	0.3

P 1 – releasing of target trees according to silvicultural requirements (removing of one, scarcely two co-dominant trees), P 2 – releasing of target trees by removing of two co-dominant individuals, P 3 – releasing of target trees by removing of three co-dominant individuals, N – the method of the promising trees, 0_C – control plot with target trees, 0_N – control plot with promising trees

(PRP) Veľká Stráž II, located near the city of Zvolen. The investigated series of PRP was established in autumn 1972, in an even-tree species oak stand that originated from natural regeneration after the widespread shelterwood felling. Until the establishment of PRP the young stand was tended by cleaning focused on removing other tree species, especially pine. The oak part of the stand was treated scarcely (Baksa 1975). At present, singly admixed hornbeam is present on the plots (Table 1).

PRPs are located in natural oak regions at the boundary of two orographic complexes: Zvolenská kotlina valley and Javorie Mountains, subcomplex Lomnianska pahorkatina Mountains, altitude 360 m a.s.l., western exposure, inclination less than 10%. Stand age at the establishment of PRP was 19 years. Research plots belong to the management complex of forest types 208 – loess beech oakwoods, management complex 25 – fertile beech oakwoods, forest type group *Fageto-Quercetum*, forest type 2309 – sedge beech oakwood with woodrush (*Carex pilosa, Luzula nemorosa*). The series of PRPs consists of 6 partial plots: P 1, P 2, P 3, where the method of target trees with different intensity of liberation of target trees was applied. On partial plot marked as N, the method of promising trees was realized. The area of these plots is 0.15 ha. The other two plots with the area of 0.075 a are control plots (with no treatment), where promising trees (0_N) and/or target trees (0_C) were marked.

By the establishment of plots the following research program was determined:

- P 1 – releasing of target trees according to silvicultural requirements (removing of one, scarcely two co-dominant trees);
- P 2 – releasing of target trees by removing two co-dominant individuals;
- P 3 – releasing of target trees by removing three co-dominant individuals;
- N – the method of promising trees;
- 0_N – control plot with promising trees;
- 0_C – control plot with target trees.

By the establishment of PRP in 1972, target trees were selected on P 1, P 2, P 3 and control plot 0_C. There were dominant and co-dominant trees with the highest quality of trunk and crown, relatively. Target trees were located at a relatively regular spacing of 8 m, while 160 individuals per ha were marked. In the framework of biometrical measurements diameter $d_{1.3}$, height of trees, height of base crown, crown size were measured and silvicultural evaluation, including both trunk and crown quality assessment, was carried out as well. Felling (besides control plots) was performed in terms of the research programme in spring 1973 (Baksa 1975).

In spring 1981 after 8-year thinning interval, the second biometrical measurement, silvicultural classification and thinning treatment were performed according to the same methodology (Remiš 1982).

Since that year, no measurements and treatments were carried out on the investigated PRP. In 1994, all partial plots were reconstructed, surviving trees thicker than 3 cm were registered and/or both target and promising trees were selected and re-marked according to Štefančík's methodology (Štefančík 1984). Promising trees are selected according to the same criteria like target trees (quality, dimension and spacing). Their frequency is usually twice higher in comparison with target trees. Promising trees are selected at younger stand age (ca. 20 to 50 years) and later on, a derived number of target trees is tended only. Consequently, promising trees are considered to be a reserve for target tree selection. The research programme has been modified in the sense that not an amount of removed competitor trees, but a different release of their crowns is considered to be a parameter of the crown liberation of target and promising trees.

The following four biometrical measurements and silvicultural classification together with thinning treatment (after 14 years) were performed in 1995, 2000, 2005 and 2010 according to the free crown thinning method (Štefančík 1984). Within their framework, besides the quantitative parameters (breast height diameter, tree height, height of base crown, crown size at horizontal projection), the trees were also evaluated according to the silvicultural and commercial classification focused on the trees of selective quality (promising and target trees).

Experimental material was processed by mathematical and statistical evaluation using Microsoft Excel software. For statistical significance of differences the ANOVA analysis was used.

RESULTS AND DISCUSSION

Tree species composition

Percentage proportions of tree species according to the basal area (G) are presented in Table 1. It can be seen that at the initial stage of our research in 1995, hornbeam with its share from 1.2% to 4.7% was the second most frequently represented tree species.

After 15 years, the proportion of hornbeam trees markedly increased by two-three times in comparison with the initial stage. It should be stated that hornbeam occupies only the suppressed level of the vertical stand profile. This increase in hornbeam proportion was higher on plots with thinnings (except for plot P 2) than on control plots (with no treatment). The above-mentioned fact is a consequence of higher light permeability of the crown

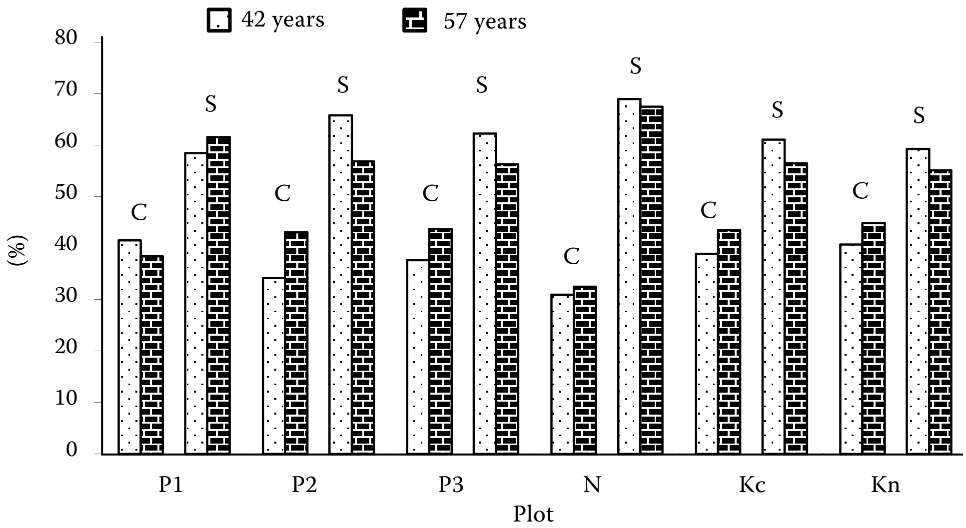

Fig. 1. Relative frequency of trees according to the level of the stand (C – crown level of the stand; S – suppressed level of the stand) on plots at the 1st measurement (in 1995) and at the 4th measurement (in 2010)

P 1 – releasing of target trees according to silvicultural requirements (removing of one, scarcely two co – dominant trees); P 2 – releasing of target trees by removing of two co – dominant individuals; P 3 – releasing of target trees by removing of three co – dominant individuals; N – the method of the promising trees; Kc – control plot with target trees; Kn – control plot with promising trees canopy due to different thinning intensity and/or crown liberation after interventions. On the other hand, the positive effect of hornbeam in the suppressed level of mixed stands on development of dominant (co-dominant) oak trees, especially target trees, was reported by Korpeľ (1973). Similarly, some authors (Leibundgut 1945; Bezačinský 1956) considered the occurrence of hornbeam in mixed hornbeam-oak stands as desirable from ecological and silvicultural aspects.

Stand structure

Stand structure was expressed by relative frequency according to the growth (tree) classes and/or by the percentage proportion of trees at the crown level of the stand (1^{st} + 2^{nd} growth class – in Fig. 1 marked as "C") and suppressed level of the stand (3^{rd} to 5^{th} growth class – in Fig. 1 marked as "S") on all plots.

The results presented in Fig. 1 showed only a small difference among the plots at the beginning of our research. It was a consequence of the low thinning intensity (not more than 12% of the basal area) realized on plots from their establishment to the beginning of our research activities. The proportion of trees at the crown level of the stand after another 15-year period was a little higher by 1.5 to 18.9% on all plots (except for P 1). Korpeľ (1973) stated that especially in young oak stands a sufficient share of intermediate (the 3^{rd} growth class) oak trees (together with secondary stand composed of hornbeam) is very important because of its silvicultural effects (prevention against epicormic branches). Therefore, the proportion of the third growth class amounting to 8.4–18.9% at the stand age of 42 years should be considered as satisfactory. Moreover, ac-

Table 2. Development of mensuration characteristics (oak + other tree species) on Veľká Stráž II PRP

Plot	Age (years)	Number of trees (ind·ha^{-1})	Basal area (m^2·ha^{-1})	Volume of the timber to the top of 7 cm (m^3·ha^{-1})	Mean	
					diameter $d_{1,3}$ (d_g) (cm)	height (h_g) (m)
P 1	19*	10,521	9.70	38.60	3.4	6.2
	42	3,426	23.83	146.95	9.6	13.9
	57	2,079	30.95	270.04	14.4^{a}	17.7^{N}
P 2	19*	10,150	12.19	50.60	3.9	6.6
	42	3,199	24.96	161.71	10.0	13.7
	57	1,760	31.29	289.00	15.5^{ab}	18.2^{N}
P 3	19*	10,873	12.79	51.06	3.9	6.5
	42	3,046	20.77	128.78	9.6	13.4
	57	1,586	27.43	240.81	15.4^{ab}	17.7^{N}
N	19*	9,085	12.50	52.19	4.2	6.7
	42	3,313	21.80	135.79	9.9	13.5
	57	2,027	29.81	258.52	15.6^{ab}	17.9^{N}
$0_C + 0_N$	19*	9,220	12.83	48.89	4.2	6.7
0_C	42	4,360	30.64	191.92	9.7	13.8
	57	2,267	37.48	335.91	15.1^{ab}	18.4^{N}
0_N	42	3,600	31.33	213.13	10.6	14.5
	57	2,106	39.08	357.44	16.4^{b}	18.9^{N}

The values with the different letter are significant on the level of α = 0.05, N^- The values are not significant on the level of α = 0.05, *data of this measurement were taken from the final report by Baksa (1975), P 1 – releasing of target trees according to silvicultural requirements (removing of one, scarcely two co-dominant trees), P 2 – releasing of target trees by removing of two co-dominant individuals, P 3 – releasing of target trees by removing of three co-dominant individuals, N – the method of the promising trees, 0_C – control plot with target trees, 0_N – control plot with promising trees

Table 3. Development of selected characteristics (oak + other tree species) on Veľká Stráž II PRP

Plot	Age (years)	Thinning intensity (%)	Mean spacing (m)	Growth area per 1 tree (m²)	Slenderness quotient	Mean periodical increment	
						($m^2 \cdot ha^{-1} \cdot year^{-1}$)	($m^3 \cdot ha^{-1} \cdot year^{-1}$)
P 1	19	2.7	1.05	0.95	–	–	–
	42	19.3	1.84	2.92	0.983	0.614	4.711
	57	1.2	2.36	4.81	0.906	0.759	6.091
P 2	19	4.7	1.07	0.99	–	–	–
	42	14.2	1.90	3.13	0.911	0.555	4.831
	57	1.8	2.56	5.68	0.865	0.503	6.274
P 3	19	5.7	1.03	0.92	–	–	–
	42	20.4	1.95	3.28	0.963	0.347	3.379
	57	2.8	2.70	6.31	0.854	0.385	4.993
N	19	11.4	1.13	1.10	–	–	–
	42	17.8	1.87	3.02	0.935	0.404	3.635
	57	2.1	2.39	4.93	0.848	0.456	5.430
$0_C + 0_N$	19	–	1.12	1.08	–	–	–
0_C	42	–	1.63	2.29	1.005	–	–
	57	–	2.26	4.41	0.967	0.456	9.599
0_N	42	–	1.79	2.78	0.959	–	–
	57	–	2.34	4.75	0.931	0.517	9.621

P 1 – releasing of target trees according to silvicultural requirements (removing of one, scarcely two co-dominant trees), P 2 – releasing of target trees by removing of two co-dominant individuals, P 3 – releasing of target trees by removing of three co-dominant individuals, N – the method of the promising trees, 0_C – control plot with target trees, 0_N – control plot with promising trees

cording to Korpeľ (1973) we are limited to help the target trees by thinning intensity in the future, without a high effect of the hornbeam secondary stand.

Development of quantitative production

The development of mensuration characteristics on Veľká Stráž II PRP is presented in Table 2. It can be seen that the relatively highest decrease of trees during the last 38 years was registered on plot P 3 (85.4%) compared to plot N (77.7%) and control plots, where the lowest decrease was found.

Besides control plots, the highest increase in basal area (G) occurred on P 1 (319%) and the lowest on P 3 (214%). The same results were obtained for the volume of timber to the top of 7 cm (V_{7b}), it means on P 1 (700%) and P 3 (472%). Although the data on self-thinning on treated plots for the period between the stand ages of 19 and 42 years are not available, we are convinced that the development of and/or differences in the above-mentioned quantitative characteristics (N, G, V_{7b}) among plots are a consequence of different methods (thinning intensity) of their tending realized by the first and second treatment, but in no case of different diameter and height structure. It is also confirmed by the fact that the values of mean diameter for all plots were very similar and differences among the treated plots were statistically insignificant (Table 2). Similar results under comparable natural conditions were also found out by Korpeľ (1974), who investigated the effects of both thinning from below and crown qualitative thinning (according to Schädelin) on basic biometrical and production changes in sessile oak stands. At the age of 41 years (after the third treatment), the number of trees was 3,840 individuals and V_{7b} was 192 $m^3 \cdot ha^{-1}$ on plots managed by crown thinning, which is only a little different from our data. Thinning intensity in crown thinning ranged from 9% to 18% (out of V_{7b}) in relation to the number of future target trees. Thinning

Table 4. An analysis of the total decrease in tree number for 15 years

Plot	Age range (years)	Tree species	Thinning and other decrease of living tree						Dead trees (self-thinning)					
			N		G		V_{7b}		N		G		V_{7b}	
			(pcs·ha^{-1})	(% TP)	(m^2·ha^{-1})	(% TP)	(m^3·ha^{-1})	(% TP)	(pcs·ha^{-1})	(% TP)	(m^2·ha^{-1})	(% TP)	(m^3·ha^{-1})	(% TP)
		oak	980	25.1	8.486	20.5	56.053	17.2	1,093	28.0	3.214	7.8	6.619	2.0
P 1	42–57	other	74	22.7	0.733	35.2	6.068	51.6	–	–	–	–	–	–
		total	1,054	24.9	9.219	21.2	62.121	18.3	1,093	25.9	3.214	7.4	6.619	2.0
		oak	739	20.3	5.486	13.6	33.839	10.2	1,287	35.3	4.454	11.0	14.046	4.2
P 2	42–57	other	73	34.3	0.586	39.8	4.187	53.1	–	–	–	–	–	–
		total	812	21.0	6.072	14.5	38.026	11.2	1,287	33.4	4.454	10.7	14.046	4.1
		oak	827	23.0	6.760	18.2	43.900	15.0	1,346	37.5	3.906	10.5	10.340	3.6
P 3	42–57	other	27	14.0	0.213	18.4	1.720	36.0	–	–	–	–	–	–
		total	854	22.5	6.973	18.2	45.620	15.4	1,346	35.6	3.906	10.2	10.340	3.5
		oak	846	25.4	7.220	19.4	47.773	15.7	1,080	32.4	3.027	8.2	8.047	2.7
N	42–57	other	173	21.8	0.273	8.5	0.067	0.6	–	–	–	–	–	–
		total	1,019	24.7	7.493	18.6	47.840	15.2	1,080	26.2	3.027	7.5	8.047	2.6
		oak	–	–	–	–	–	–	2,080	50.5	7.321	16.7	26.133	7.3
0_C	42–57	other	–	–	–	–	–	–	13	5.4	0.013	1.4	–	–
		total	–	–	–	–	–	–	2,093	48.0	7.334	16.4	26.133	7.2
		oak	–	–	–	–	–	–	1,494	46.3	6.440	14.9	27.013	7.3
0_N	42–57	other	–	–	–	–	–	–	–	–	–	–	–	–
		total	–	–	–	–	–	–	1,494	41.5	6.440	14.1	27.013	7.0

P 1 – releasing of target trees according to silvicultural requirements (removing of one, scarcely two co-dominant trees), P 2 – releasing of target trees by removing of two co-dominant individuals, P 3 – releasing of target trees by removing of three co-dominant individuals, N – the method of the promising trees, 0_C – control plot with target trees, 0_N – control plot with promising trees, N – number of trees per hectare, G – basal area, V_{7b} – volume of timber to the top of 7 cm

Table 5. Development of quantitative production of the stand over 15 years

Plot	Age range (years)	Tree species	Total decrease of trees						Total production				
			N		G		V_{7b}		N	G		V_{7b}	
			(pcs·ha^{-1})	(% TP)	(m^2·ha^{-1})	(% TP)	(m^3·ha^{-1})	(% TP)	(pcs·ha^{-1})	(m^2·ha^{-1})	(index of total stand)	(m^3·ha^{-1})	(index of total stand)
P 1	42–57	oak	2,073	53.1	11.700	28.3	62.672	19.2	3,900	41.307	1.453	327.019	1.863
		other	74	22.7	0.733	35.2	6.068	51.6	326	2.080	1.914	11.761	2.073
		total	2,147	50.8	12.433	28.6	68.740	20.3	4,226	43.387	1.470	338.780	1.870
P 2	42–57	oak	2,026	55.6	9.940	24.6	47.885	14.4	3,646	40.340	1.432	333.185	1.849
		other	73	34.3	0.586	39.8	4.187	53.1	213	1.473	1.589	7.887	1.737
		total	2,099	54.4	10.526	25.2	52.072	15.3	3,859	41.813	1.437	341.072	1.847
P 3	42–57	oak	2,173	60.5	10.666	28.7	54.240	18.6	3,593	37.146	1.450	291.987	1.841
		other	27	14.0	0.213	18.4	1.720	36.0	193	1.160	2.382	4.780	2.676
		total	2,200	58.1	10.879	28.4	55.960	18.9	3,786	38.306	1.468	296.767	1.850
N	42–57	oak	1,926	57.8	10.247	27.6	55.820	18.4	3,333	37.134	1.470	303.973	1.881
		other	173	21.8	0.273	8.5	0.067	0.6	793	3.193	2.520	10.434	11.593
		total	2,099	50.9	10.520	26.1	55.887	17.8	4,126	40.327	1.520	314.407	1.935
0_C	42–57	oak	2,080	50.5	7.321	16.7	26.133	7.3	4,120	43.854	1.448	360.106	1.877
		other	13	5.4	0.013	1.4	–	–	240	0.960	2.667	1.933	36.472
		total	2,093	48.0	7.334	16.4	26.133	7.2	4,360	44.814	1.463	362.039	1.886
0_N	42–57	oak	1,494	46.3	6.440	14.9	27.013	7.3	3,227	43.080	1.439	369.000	1.795
		other	–	–	–	–	–	–	373	2.440	1.743	15.454	2.030
		total	1,494	41.5	6.440	14.1	27.013	7.0	3,600	45.520	1.453	384.454	1.804

P 1 – releasing of target trees according to silvicultural requirements (removing of one, scarcely two co-dominant trees), P 2 – releasing of target trees by removing of two co-dominant individuals, P 3 – releasing of target trees by removing of three co-dominant individuals, N – the method of the promising trees, 0_C – control plot with target trees, 0_N – control plot with promising trees, N – number of trees per hectare, G – basal area, V_{7b} – volume of timber to the top of 7 cm intensity on our plots at the age of 42 years (not presented in Table 2) expressed by V_{7b} ranged from 12.5% to 19.7% (Štefančík 1998). For example, in former Yugoslavia Dekanič (1980) reported the growing stock of 300.6 $m^3.ha^{-1}$ on treated plot and 238.8 $m^3 \cdot ha^{-1}$ on control plot at the oak stand age of 42 years. Mean annual volume increment was 7.1 $m^3 \cdot ha^{-1} \cdot year^{-1}$, with thinning intensity of 27%.

Chroust (2007) published the following values of N, G and V_{7b} for 58-year-old stand of pedunculate oak on control plot: 1,537 individuals per hectare, 36.70 $m^2 \cdot ha^{-1}$ and 367.0 $m^3 \cdot ha^{-1}$, respectively, contrary to our results on plot 0_N 2,106; 39.08 $m^2 \cdot ha^{-1}$ and 357.44 $m^3 \cdot ha^{-1}$, respectively. The mean annual periodic basal area and volume increment on plots managed by crown thinning by the method of target trees were 0.76 $m^3 \cdot ha^{-1} \cdot year^{-1}$ and 8.80 $m^3 \cdot ha^{-1} \cdot year^{-1}$, which is similar to our results found on plot P 1, i.e. 0.759 and 6.091, respectively. Dong et al. (1997) reported from Elmstein-Nord plot at the stand age of 59 years for 172 target trees the following parameters: N 1,228 individuals per hectare, mean height 16.8 m, mean diameter 14.2 cm, G 19.4 $m^2 \cdot ha^{-1}$, V_{7b} 183 $m^3 \cdot ha^{-1}$.

Other selected characteristics presented in Table 3 reflected the quantitative characteristics presented in Table 2, as well as the management regime applied to investigated plots up to now. It is clear that some of them (mean spacing, growth area per 1 tree) were derived from the number of residual trees on plots. As for the mean periodical basal area increment (i_g), the highest values (at the age of 57 years) were found on plot P 1 (0.759 $m^2 \cdot ha^{-1}$.year), where the total thinning intensity (for 38-year period) was 33.6%. On the other hand, the lowest values were recorded on plot P 3 (0.385 $m^2 \cdot ha^{-1}$.year), although the total thinning intensity (31.9%) was similar to P 1. We suggest that differences between the two above-mentioned plots in mean diameter (d_g) are very similar, and statistically insignificant ($\alpha = 0.05$). It is interesting that d_g of plot P 3 was even higher by 1.0 cm in comparison with plot P 1. It means that it should be a consequence of different thinning regime (intensity), but not the influence of the mean diameter, as we already stated earlier in the case of different G and V_{7b}. As for the mean periodical volume increment (i_v), the lowest value was obtained on plot P 3 again (4.993 $m^3 \cdot ha^{-1}$ per $year^{-1}$). It is interesting that, contrary to the lowest total thinning intensity during the last 15 years as well as in the entire investigated period (38 years), the highest i_v (only treated plots were compared) was found on plot P 2 (6.274 $m^3 \cdot ha^{-1} \cdot year^{-1}$).

Table 4 shows a decrease due to thinning and another decrease of living trees (windthrow, snowbreak), as well as a reduction due to self-thinning expressed by the proportion out of the total production (TP). According to basal area (G), the highest decrease was found on plot P 1 (21.2% out of TP) and the lowest on plot P 2 (14.5%), which is in accordance with total thinning intensity (38-year period) on these plots. If we compare just treated plots, the highest decrease by self-thinning was found on plot P 2 (10.7%) and the lowest on plot P 1 (7.4%), which corresponds to thinning intensity again. The same tendency among plots was shown by values related to the total decrease of trees (Table 5).

Unfortunately, detailed data from the previous measurement (at the stand age of 19 and 27 years) are not available. Therefore, the exact results of total production for only a 15-year period are presented in Tables 4 and 5. The best results (comparison of treated plots) were obtained for plot P 1 and P 2. The lowest values of total basal area production and total volume production were found out on plot P 3.

Slenderness quotient

The values of slenderness quotient presented in Table 3 were calculated from the 100 largest trees (according to breast height diameter) per hectare for each plot. Although the differences among plots were not either very distinctive or statistically significant ($\alpha = 0.05$), nevertheless, the most favourable values were found on plots N, P 3 and P 2. Consequently, the effect of long-term tending was evident on treated plots in comparison with control plots. The mentioned quotient should be considered as favourable for oak. Dudzinska and Tomusiak (2000) presented the mean value of the slenderness quotient 0.81 for 384 investigated oaks (age 26–140 years), with variability coefficient 18.5%. Our values were lower when they ranged from 3.3% to 7.8%. The above-mentioned authors stated that the mean values of slenderness quotient mostly depend on the mean breast height diameter ($r = -0.913$). The values on our plots ranged from $r = -0.458$ to -0.923, when the highest correlation was found on the following plots: 0_C, P 1 and P 3.

Development of qualitative production by the method of promising and target trees

Table 6 documents the development of trees of selective quality – TSQ (promising trees and/or target trees), which are the goal of silvicultural in-

Table 6. Development of the trees of selective quality (promising and target trees)

Plot	Age (years)	Number of trees (pcs·ha^{-1})	Basal area		Volume of the timber to the top of 7 cm		Mean	
			(m^2·ha^{-1})	% out of the main stand	(m^3·ha^{-1})	% out of the main stand	diameter $d_{1,3}$ (d_g)(cm)	height (h_g) (m)
P 1	19*	160	0.30	3.1	1.17	3.0	4.8	6.8
	42	173	3.29	13.8	27.36	18.6	15.5	17.2
	57	173	6.20	20.0	64.95	24.1	21.4^{N}	21.2^{abc}
P 2	19*	160	0.38	3.1	1.60	3.2	5.4	7.5
	42	166	3.61	14.5	30.72	19.0	16.5	17.4
	57	160	6.26	20.0	68.51	23.7	22.3^{N}	21.9^{b}
P 3	19*	160	0.36	2.8	1.52	3.0	5.4	7.4
	42	133	2.69	12.9	22.65	17.6	16.1	17.3
	57	120	4.67	17.0	48.76	20.2	22.3^{N}	20.8^{c}
N	19*	1,161	2.48	19.9	10.92	20.9	5.2	7.6
	42	320	6.46	29.6	53.62	39.5	16.1	17.1
	57	300	11.57	38.8	121.24	46.9	22.2^{N}	20.9^{ac}
0_C	19*	160	0.35	2.8	1.47	3.0	5.2	7.5
	42	173	3.17	10.4	26.45	13.8	15.2	17.3
	57	160	5.77	15.4	62.95	18.7	21.4^{N}	21.7^{abc}
0_N	19*	1,074	2.27	17.7	9.73	19.9	5.1	7.5
	42	453	8.99	28.7	75.80	35.6	15.9	17.4
	57	387	12.99	33.2	135.19	37.8	20.7^{N}	20.9^{abc}

The values with the different letter are significant on the level of α = 0.05, N – values are not significant on the level of α = 0.05, *data of this measurement were taken from the final report by Baksa (1975), P 1 – releasing of target trees according to silvicultural requirements (removing of one, scarcely two co-dominant trees), P 2 – releasing of target trees by removing of two co-dominant individuals, P 3 – releasing of target trees by removing of three co-dominant individuals, N – the method of the promising trees, 0_C – control plot with target trees, 0_N – control plot with promising trees

terest of forest managers, as the main bearers of stand quality and quantity and also from the aspect of ecological stability. We point out that the TSQ have been selected on the basis of developed criterion (Štefančík 1984) at the phase of pole-stage stand.

It can be seen that on plots with target trees, their amount markedly changed (decreased) only on P 3. It was caused by the fact that at the establishment of the plot in 1972 a production model with 160 target trees·ha^{-1} was used, and it determined their selection. During the reconstruction of PRP in 1995, the selection of TSQ was carried out according to the above-mentioned Štefančík's criteria, where the quality of target trees (considering especially diameter and spacing) was the first-rate condition contrary to their exactly determined number. Besides this fact, an amount of qualitative co-dominant trees on P 3 was limited because of previous heavy thinning treatments.

The number of selected TSQ corresponds with data published in literature, but in comparison with foreign literature it is higher. For instance, Baksa (1975) presented 100 to 320 target trees·ha^{-1} in relation to rotation and goal diameter. Korpeľ (1974) recommended 150 future mature trees·ha^{-1} and stated that the amount of these trees should not be higher than 300 individuals per hectare in stands older than 40 years. Similarly, Slodičák et al. (2009) investigated 150 target trees·ha^{-1} under comparable natural conditions, on plots located in the southern part of Bohemia. Dong et al. (1997) considered 80–100 target trees·ha^{-1} to be a sufficient number and Roy (1975) also considered a low

Table 7. Mean annual diameter increment (i_d) of the trees of selective quality on Veľká Stráž II PRP

Plot	P 1	P 2	P 3	N	0_C	0_N
i_d (1995–1999)	$3.76^{abc} \pm 0.70$	$3.90^{b} \pm 0.75$	$3.88^{abc} \pm 0.96$	$3.86^{ab} \pm 1.10$	$3.45^{abc} \pm 1.02$	$3.02^{c} \pm 0.80$
i_d (2000–2004)	$4.39^{b} \pm 0.55$	$3.88^{bcd} \pm 0.92$	$4.44^{ab} \pm 1.02$	$4.46^{bd} \pm 1.02$	$3.93^{bcd} \pm 0.88$	$3.23^{c} \pm 0.88$
i_d (2005–2009)	$3.28^{abc} \pm 0.62$	$3.14^{abc} \pm 0.77$	$3.29^{abc} \pm 0.90$	$3.40^{ab} \pm 0.95$	$3.38^{ad} \pm 1.04$	$2.58^{cd} \pm 0.80$
i_d (1995–2009)	$3.81^{b} \pm 0.53$	$3.66^{bcd} \pm 0.71$	$3.87^{ab} \pm 0.85$	$3.95^{bd} \pm 0.91$	$3.67^{bcd} \pm 0.89$	$3.06^{c} \pm 0.62$

The values in rows with the different letter are significant on the level of $\alpha = 0.05$, P 1 – releasing of target trees according to silvicultural requirements (removing of one, scarcely two co-dominant trees), P 2 – releasing of target trees by removing of two co-dominant individuals, P 3 – releasing of target trees by removing of three co-dominant individuals, N – the method of the promising trees, 0_C – control plot with target trees, 0_N – control plot with promising trees

number of target trees (70 individuals per hectare) as sufficient. Lüpke and Welcker (1998) found only 65 target trees·ha^{-1} in a 91-year-old untouched mixed oak stand.

As for the quantitative characteristics of TSQ, the highest mean diameter (d_g) was found on plots P 2 and P 3 (22.3 cm), and the lowest on control plot 0_N (20.7 cm). The values obtained by Dong et al. (1997) for 172 target trees at the stand age of 59 years were d_g 22.5 cm and h_g 21.5 m. Comparing the plots tended by the method of target trees only (P 1, P 2, P 3), both G and V_{7b} correspond to the number of these ones, i.e. the highest values were found on plot P 2 and the lowest on plot P 3.

The share of TSQ in the main stand is an important silvicultural characteristic (Table 6). An appropriate effect of thinnings on treated plots (P 1, P 2, P 3) in comparison with control plot (0_C) is evident. It can be seen from the volume of timber to the top of 7 cm that TSQ at the age of 42 years accounted for 17.6% to 39.5% of the main stand. Similar results were obtained by Korpeľ (1974), who reported the volume share of expectants in the total stand volume (according to Schädelin's method) to be 17% at the stand age of 33 years (future mature trees) and 36% at the age of 46 years. According to both diameter and height increment of the total stand, the most intensive increment (according to increment percentage) was achieved on P 1 and the lowest in plot N and control plot 0_C. The same results were obtained in the case of TSQ. The above-mentioned trend corresponds to development found out at the second thinning in 1981, when the highest increment reaction was recorded also on the plot with the lowest mean diameter, it means on P 1 (Remiš 1982).

Very interesting results were obtained for the mean annual periodical diameter increment (i_d) of TSQ (Table 7). Apart from the period 1995–1999, the highest i_d was found on plot N, it means on the plot with the highest total thinning intensity. The same results were also published by Makineči (2005) for Demirkoy forest (Turkey), where a heavily thinned plot in sessile oak stand showed the highest diameter increment. It is interesting that i_d higher than 2 mm was registered also on control plots, which is in accordance with Utschig and Pretzsch (2001), who found the annual diameter increment exceeding 2 mm even on unthinned plots in a 48-year-old oak stand near Kaiserslautern (Germany). Similar results were published by Chroust (2007), when his values of i_d at the stand age of 43–58 years were 3.0 ± 0.8 mm on control plots, 3.4 ± 1.4 mm on a plot with positive selective thinning, and 3.8 ± 1.2 mm on a plot with marked target trees.

CONCLUSION

According to the results of quantitative evaluation of sessile oak stand after six thinning treatments the following facts were ascertained:

- the highest mean diameter and height, basal area, volume of timber to the top of 7 cm and mean periodical volume increment (on plots with tending) were recorded on plot P 2, where the method of target trees was applied. By the first treatment (at the stand age of 19 years) target trees were released by removing two competitor trees;
- the lowest values of the above-mentioned mensuration characteristics were ascertained on P 3 (except for d_g), where target trees were released by removing three individuals;
- comparison of total thinning intensity (38-year period) according to basal area showed the heaviest thinning on plot N, followed by P 1 and P 3, and the lowest on P 2;

– number of trees of selective quality (TSQ) was the lowest on P 3 (120 trees·ha^{-1}) and their share in the main stand according to basal area as well as the volume of timber to the top of 7 cm was the lowest in comparison with the other treated plots. Plot P 2 showed the highest mean diameter and the tallest mean height of TSQ. On the other hand, taking into account the thinned plots only, the highest mean annual diameter increment of TSQ (the last 15-year period) was registered on plot N, contrary to plot P 2 with the lowest increment;
– on plots tended by the method of target trees, the best quantitative characteristics were recorded on P 2 and P 1.

On the basis of preliminary results after 6 thinning treatments, it could be stated that from the quantitative point of view, the worst results (according to the majority of investigated parameters) were obtained on plots where target trees were heavily released at the initial stage of the research (stand age 19 years) by removing three individuals in favour of target trees. On the contrary, better outcomes were obtained on plots with moderate thinning intensity ranging between 10 and 15% (according to G), which corresponds to results published by Korpeľ (1974).

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