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ORIGINAL PAPER

Comparison of growth of northern red oak (*Quercus rubra* L.) and durmast oak (*Quercus petraea* [Mattusch.] Liebl.) under similar growth conditions

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Abstract

The impacts of climate change on forest stands are manifested in different ways and intensity. Changes in the species composition of forest stands due to the different tolerance of forest species to the effects of climate change are one of the consequences too. In this context, introduced tree species are often mentioned as a possible replacement for dying autochthonous species. Of the deciduous species, it is mainly northern red oak. The aim of this paper is to compare selected quantitative (number of trees, basal area, merchantable volume, basal area increment and volume increment) and qualitative (crop trees) characteristics in one stand of the northern red oak at the age of 54 years and in two stands of durmast oak (age 57 and 58 years) in comparable site conditions. Achieved results showed higher values in all investigated quantitative parameters in the northern red oak stand compared to durmast oak stands. The merchantable volume in the northern red oak stand was 473 m^3 per hectare in the tended subplots and 742 $m^3\ ha^{-1}$ in the control ones. On the subplots with durmast oak, it was only from 228 to 289 $m^3\ ha^{-1}$ in the subplots with thinning and 226 to 357 $m^3\ ha^{-1}$ in the control areas. The same results were obtained for the category of crop trees. It means 230 $m^3\ ha^{-1}$ for the northern red oak and 28 to 121 $m^3\ ha^{-1}$ for durmast oak. The well-known fact about the higher quantitative production of the northern red oak compared to durmast oak was confirmed.

Key words: stand structure; quantitative production; qualitative parameters; crop trees

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1. Introduction

Northern red oak (*Quercus rubra* L.) was introduced to Europe from North America already in the 17th century (Kubát 2002), and/or to Slovakia in the middle of the 19th century (Benčať et al. 1984). At first, it was planted in parks and in the 20th century also in forest stands as an economic tree species (Réh & Réh 1997). In Slovakia, it currently occupies an area of 2,193 ha with a proportion of 0.11% of the total species composition (Šebeň 2017).

From a production view, the possibilities of growing northern red oak are mainly in the southern regions of Slovakia, i.e. the natural conditions are suitable for it in the 1st and 2nd forest vegetation zone. It was usually planted in the group of forest types *Carpineto-Quercetum*, but Tokár (1985), for example, states that in the region of the Little Carpathians it was mostly planted in the group of forest types *Corneto-Quercetum*, at altitudes up to 200 m. In Bohemia, it was similar. There are data on its planting up to 300 m (Kupka et al. 2018). In contrast, in Romania it was also planted at higher altitudes up to 780 m (Sandi & Nicolescu 2011).

Northern red oak is a fast-growing, light-demanding and undemanding in terms of soil requirements tree species that requires moderately moist habitats (Kleiner et al. 1992). It is characterized by undemanding ecological requirements and resistance to harmful agents and low temperatures (Benčať 2002). At the same time, it is considered a promising tree species in connection with changed ecological conditions due to climate change (Thomasius 1991; Dyderski et al. 2020; Kupka & Vopálka-Melicharová 2020). Although its proportion

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in the Slovak forests is small (Šebeň 2017), it can be assumed that its importance and application will increase in the future with regard to the mentioned above (Miltner & Kupka 2016; Nicolescu et al. 2020). Next to Douglas fir, it is the most planted introduced species into the forest environment (Réh & Réh 1997). In Slovakia, in the past, introduced tree species were mostly grown in the form of industrial plantations, but also in a specific category of intensive stands with an ornamental wood texture (Remiš & Soják 1986; Réh & Réh 1997).

Northern red oak is considered an important introduced species in many countries (Réh 1999; Sandi & Nicolescu 2011; Gubka & Pittner 2014; Miltner et al. 2016; Kupka et al. 2018; Nicolescu et al. 2020). In addition, it is considered the tree species resistant to the effects of polluted air and, in the 1980s, also the species with minimal damage due to tracheomycosis (Réh & Réh 1997; Kupka & Miltner 2017), better known as "mass oak dieback". According to some authors (Štefančík 1992; Réh 1999), this species has its rationale also in special purpose forests with recreational or the spa-therapeutic and aesthetic function. It is also well known for its good use in the wood industry (Réh & Réh 1997) and the biological activity of bark extracts (Tanase et al. 2022).

The issue of research related to growth and development of the northern red oak in Slovakia was already addressed by research in the 1960s and 1970s (Réh 1976; Tokár 1979). Due to rapid growth at a young age and higher volume production compared to domestic oak species (Kouba & Zahradník 2011; Podrázský et al. 2014), relatively low demands on soil conditions (Holubík et al. 2014), positive impact on the soil environment (Podrázský & Remeš 2010), good natural regeneration (Myczko et al. 2014; Miltner & Kupka 2016; Woziwoda et al. 2019; Chmura 2020), this introduced species has become the subject of interest and intensive research from various aspects (Réh & Réh 1997; Tokár 1998; Gubka & Sklenár 2006; Sandi & Nicolescu 2011; Slávik & Štefančík 2015; Viewegh et al. 2016; Kupka et al. 2018; Nosko et al. 2021).

In the past, several long-term research plots were established where the growth and quantitative production of northern red oak were investigated (Tokár 1987), including the evaluation of an impact of cleaning interventions (Ușurelu et al. 2019), long-term tending (Réh & Réh 1997; Tokár 1998; Réh 1999) on stand structure (Gubka & Sklenár 2006), on the quality of individual trees (Gubka & Pittner 2014; Kupka et al. 2018) and production (Tokár 1998; Štefančík 2011, 2018), and/or the spa-therapeutic function of the stands (Štefančík 1992, 2011). Moreover, works dealing with changes in the proportion of tree classes and the development of mortality of individual trees (Ward & Stephens 1994; Štefančík 2011) and/or the influence of soil nutrient content on mortality (Demchik & Sharpe 2000), the composition of the herbaceous layer (Viewegh et al. 2016; Chmura 2020) and the chemical properties of the soil (Miltner et al. 2016, 2017; Ferré & Comolli 2020; Stanek et al. 2020) in the stands of this species are known too.

The aim of this paper is to evaluate and compare selected quantitative characteristics (basal area, merchantable volume, mean periodical basal and merchantable volume increment) and some parameters of crop trees (percentage out of the main stand) in one stand of the northern red oak and two stands of the durmast oak in comparable site conditions in Slovakia. To achieve this, we proposed a working hypothesis that assumes higher quantitative production in the northern red oak stand compared to durmast oak stands. In order to exclude the influence of tending interventions, only control plots (without interventions) were compared.

2. Material and methods

2.1. Study area

The object of this research were the series of long-term research plots (LTPs) in Slovakia, specifically at three localities (Dudince, Veľká Stráž and Novačany). The first series is a stand of the northern red oak at LTP Dudince (48°09´40.93˝N and 18°53´11.79˝E), which was established in 1971 from artificial regeneration by row planting of 2-year-old plants at a distance of 1 m between rows and at a spacing distance of 0.75 m in rows. The others are two stands of durmast oak (*Quercus petraea* [Mattusch.] Liebl.), which originated from natural regeneration (Veľká Stráž 48°34´43.89˝N and 19°05´28.72˝E, Novačany 48°41´01.75˝N and 21°02´06.66˝E). These LTPs were established in 1972 and 1984, respectively. Table 1 provides basic data, a more detailed description can be found in the papers of Štefančík (2011, 2021) and Štefančík & Strmeň (2012).

2.2. Data colection

LTP Dudince consists of two subplots (I–2, I–0). On the subplot I–2 (an area of 0.18 ha), a positive crown thinning was carried out during the first three interventions, but from the 4th to the 7th intervention, measures were also carried out in the suppressed level of the stand (understorey). Thus, further thinnings had the properties of Štefančík's free crown thinning (Štefančík 1984). This means that the intervention was aimed at supporting the promising, and/or crop trees, which are the main bearers of quantitative and qualitative production. So far, 7 interventions have been carried out on this subplots with an interval of 5 years. Subplot I–0 (an area of 0.14 ha) serves as a control, i.e. without planned interventions.

LTP Veľká Stráž consists of 6 subplots: P1, P2, P3 – where the method of crop trees has been applied since

Table 1. Basic data on long-term research plots.

Long-term research plot	Subplot	Age [year]	Altitude [m]	Mean temp. [°C]	Mean precip. [mm]	Forest altitudinal zone	Soil unit	Tree species
Dudince	I–2 I–0	54	150	9.5	560	2nd beech-oak	Haplic Cambisol	Northern red oak
Veľká Stráž	P–1 P–2 P–3 N 0c 0n	57	350	8.1	690	2nd beech-oak	Eutric Cambisol	Durmast oak
Novačany	N–1 N–2 N–0	58	300	9.1	620	2nd beech-oak	Haplic Cambisol (Luvic)	Durmast oak

Note: I–2, P–1, P–2, P–3, N, N–1, N–2: subplots with the free (positive) crown thinning (Štefančík 1984); I–0, 0c, 0n, N–0: control subplots with no intervention.

this LTP establishing (19 years), with different intensity of liberation of crop tree crowns (160 trees ha^{-1}). Plot N – where the method of promising trees was implemented (1,161 trees ha^{-1} at the beginning of the research at the age of 19 years, later from the age of 62 years it changed to the method of crop trees). The size of these subplots is 0.15 ha. So far, 6 interventions with an interval of 5 years have been carried out on these subplots. Other two subplots are control ones (without interventions) with an area of 0.075 ha. Here, 1,074 promising trees were marked on 1 ha when these subplots were established (subplot 0n), and/or 160 crop trees per hectare (subplot 0c).

When LTP was established at the age of 19 years, the following research scheme was defined:

P1 marking of crop trees (160 trees ha^{-1}) and their release by removing one competing tree from the crown level;

P2 marking of crop trees (160 trees ha^{-1}) and their release by removing two competing trees from the stand level;

P3 marking of crop trees (160 trees ha^{-1}) and their release by removing three competing trees from the stand level;

N marking of promising trees (1,161 trees ha^{-1}) and their release as needed; from the stand age of 62 years, the method of crop trees applied;

0n control subplot with marked promising trees (1,074 trees ha^{-1}); from the age of 62 years, the method of crop trees with a marking of 187 trees ha^{-1} of crop trees;

0c control subplot with a marking of crop trees (160 trees ha^{-1}).

LTP Novačany consists of three subplots (N–1, N–2, N–0), where each has an area of 0.21 ha. On one of them (marked as N–1), from the view of phytotechnics, a quality crown thinning with positive selection is carried out, i.e. the method of crop trees (CT). In the first intervention (moderate intensity) on this subplot, it was an alternative in which each CT was released by removing one "most competitive" co-dominant or dominant tree, exceptionally an intermediate tree only when it was damaging the crown of the CT. Only during the 3rd intervention, subdominat trees were removed when affected, but to an unavoidable extent. Within the second subplot (marked as N–2), in the first intervention (heavier compared to the subplot N–1), the same positive crown thinning was carried out by the method of crop trees, but with the alternative where each CT was released by removing two "most competitive" dominant or co-dominant individuals and subdominant trees from the above mentioned reasons. Similar to the N–1 subplot, only during the 3rd and 4th intervention, the understorey was also intervened to an unavoidable extent. So far, 8 interventions with an interval of 5 years have been carried out on these subplots. The third subplot (N–0) serves as the control, i.e. without intentional interventions.

Standard biometric measurements and evaluations of quantitative parameters (number of trees, diameter $d_{1.3}$, tree height and crown base height) were performed on all subplots. Moreover, trees were classified according to growth (tree) classes, and trees of selection quality (promising and crop trees) were also determined according to well-known criterion (Štefančík 1984). Determining selection quality trees (promising or target) is based on three key criteria (quality, dimension, spacing). Target trees are re-evaluated according to the mentioned three criteria at each measurement. If they do not fulfil at least one of them, they are excluded from this category. Therefore, their number per hectare is an important indicator of the quality of the stand.

2.3. Data analysis

Height curves were levelled by the Michailoff's function (Michailoff 1943). According to the measured diameters and heights from the levelled height curves, the merchantable volumes in the volume unit without bark were calculated. Analytical forms of volume equations were used for this purpose (Petráš & Pajtík 1991), specifically the durmast oak equation was used for all of them. The data from the research plots – merchantable volume, basal area and the number of trees were calculated to 1 ha. In addition, mean stand variables were also calculated – mean diameter and height. Data obtained were processed by standard biometric and statistical methods using the

QC Expert software (Kupka 2013) and also usual formulas for calculating quantitative production parameters (Šmelko et al. 2003; Scheer & Sedmák 2014). To determine the statistical significance of the differences, a one-way analysis of variance (ANOVA) was used.

3. Results

3.1. Diameter structure and height curves

Diameter maturity of compared stands, and/or only of control subplots without intervention is characterized by curves of absolute diameter frequencies (Fig. 1).

It can be seen that the thickest trees are located on the control subplot with northern red oak (I–0), specifically from the diameter of breast height (dbh) more than 22 cm. At the same time, we found out the largest mean diameter $d_g = 22.5$ cm on this subplot. On subplots with durmast oak, it was only 15.1 cm and 16.4 cm (LTP Veľká Stráž), and/or 16.8 cm (LTP Novačany). The differences between the subplot with northern red oak (LTP Dudince) and other control subplots were statistically significant ($p < 0.05$).

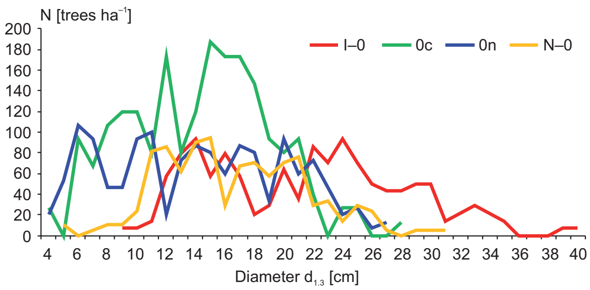

Fig. 1. Diameter frequency distribution on control subplots.

Similarly, the comparison of height curves from the control subplots (Fig. 2) showed a significant difference between the northern red oak and localities with durmast oak (LTP Novačany and LTP Veľká Stráž). The differences were also statistically significant ($p < 0.05$), while the differences between the subplots with durmast oak were small and not statistically significant ($p > 0.05$).

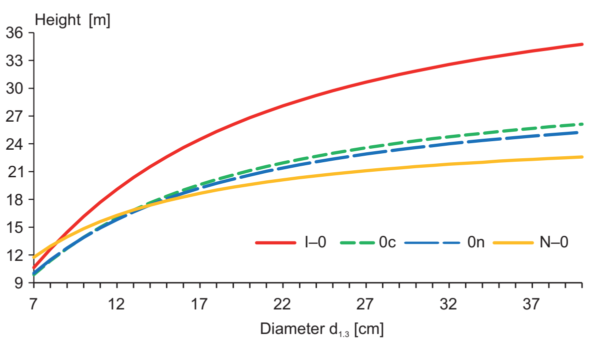

Fig. 2. Height curves on investigated control subplots.

3.2. Quantitative production

Table 2 shows selected quantitative characteristics of the compared stands of northern red oak and durmast oak. Despite the slight difference in age, there were more significant differences in the investigated parameters. The lowest number of trees per hectare was found at LTP Dudince (northern red oak) and LTP Novačany (durmast oak). We recorded a higher number of trees in the 57-year-old stand of durmast oak at the Veľká Stráž locality, where the number of trees in the managed subplots ranged from 1,586 to 2,079 trees ha^{-1} and in the control subplots 2,106 and 2,267 trees ha^{-1}. In the northern red oak stand at the Dudince locality, the number of trees was 1,300 and 1,133 trees per hectare, which is less than at the Veľká Stráž locality (durmast oak), but more compared to Novačany (durmast oak), despite the fact that the stand from LTP Dudince originated from artificial regeneration, i.e. with a much lower initial state.

Table 2. Mensuration characteristics on long-term research plots.

Subplot	Age [year]	Number of trees [tree ha^{-1}]	Basal area [m^2 ha^{-1}]	Merchantable volume [m^3 ha^{-1}]	Mean periodical increment i_G [m^2 ha^{-1} year^{-1}]	Mean periodical increment i_{V7b} [m^3 ha^{-1} year^{-1}]
I–2	54	1,133	34.9	473	1.187	20.447
I–0		1,300	51.6	742	1.376	27.247
P–1	57	2,079	31.0	270	0.759	6.091
P–2		1,760	31.3	289	0.503	6.274
P–3		1,586	27.4	241	0.385	4.993
N		2,027	29.8	259	0.456	5.430
0c		2,267	37.5	336	0.456	9.599
0n		2,106	39.1	357	0.517	9.621
N–1	58	1,491	25.4	230	0.423	8.921
N–2		1,186	24.2	228	0.527	9.956
N–0		1,090	24.1	226	0.234	7.121

Note: For explanation see Table 1; i_G – mean periodical increment of basal area; i_{V7b} – mean periodical increment of merchantable volume.

Despite the slightly lower age of the northern red oak stand, we found out higher values of the basal area and the merchantable volume compared to the durmast oak (Table 2). In the case of the merchantable volume, values were even significantly higher. This is due to the value of mean variables (diameter $d_{1.3}$ and height) from which the mentioned parameters are calculated. These were always higher in the northern red oak stand compared to the durmast oak.

We were interested in whether the differences between the control subplots were also showed in the relation between the dbh and the volume of crowns (Fig. 3). A correlation analysis showed the closest relation on the control subplot I–0 ($r = 0.78$). On the contrary, we found out the lowest dependence ($r = 0.41$) on the 0n subplot. It turned out that when the dbh was larger than 27 cm, trees of the northern red oak at LTP Dudince had the highest crown volume. Likewise, with regard to the average crown volume on control subplots, we found out the largest on the mentioned subplot I–0 (55.6 m^3), while the differences from the other subplots were also statistically significant ($p < 0.05$) except for the subplot N–0 (53.7 m^3). The smallest crown volume (17.4 and 19.7 m^3) was found out in control subplots from LTP Veľká Stráž.

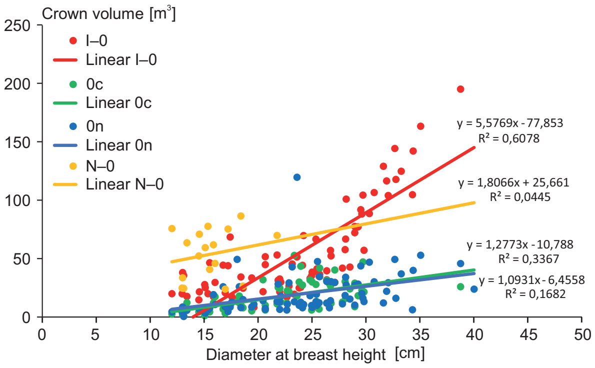

Fig. 3. The relationship between dbh and crown volume.

3.3. Qualitative production

We expressed the qualitative production (Table 3) through the selective quality trees (promising or crop trees). In practice, they represent the highest quality component of the stand, which are the crucial bearers of value production. The highest number of crop trees was found on the LTP with the northern red oak (LTP Dudince). Crop trees in the northern red oak stand (subplots I–2 and I–0) exceeded the values from the durmast oak stands in terms of the basal area, merchantable volume and mean stand variables (d_g and h_g). The proportion of crop trees from the main stand, which in the case of northern red oak is several times higher than subplots with durmast oak, is an important indicator.

4. Discussion

4.1. Quantitative production

The course of the diameter frequency curves pointed to a distribution typical for middle-aged stands, i.e. with an indication of a slight left-sided distribution. The stand of northern red oak exceeded the frequency in the thickest dimensions in comparison to stands with durmast oak, which was also confirmed by other studies (Gubka & Sklenár 2006). Better results of the northern red oak compared to the durmast oak were also confirmed in terms of height growth, which is represented by height curves. The differences were evident and statistically significant. Even more significant differences in favour of the northern red oak were found out when comparing height curves, which significantly affect several derived quantitative variables (basal area, merchantable volume, etc.).

Nicolescu et al. (2020) state that in the best sites, by applying a heavy crown thinning, the mean diameter of the northern red oak can be reached already at the age of 50 years. We found out a value of 22.5 cm and the mean height 28.4 m at the age of 54 years on the control subplot. However, the value of mean height found out by us at the age of 39 years was the same as reported by Bauer (1953) at the age of 40 years, i.e. 21.0 m. The height structure of the stand (sociological position) is also important from the ecological view of the stand, because it also affects the growth of oak stands in relation to the soil water and the stand density (Trouvé et al. 2017).

The number of trees (stand density) is an important parameter, especially in the current manifestations of climate change, which has an impact on growth (Nechita & Chiriloaei 2018; Bello et al. 2019) and oak sensitivity to drought (Steckel et al. 2020).

We found out the lowest number of trees per hectare in the durmast oak control subplot (LTP Novačany), mainly due to the fact that in the 1980s this stand was affected by a tracheomycosis disease of fungal origin (mass dieback of oaks). As a result, there was a significant decrease in trees at this locality (Štefančík & Strmeň 2012). On the contrary, the highest number of trees was at LTP Veľká Stráž, where the decline of oaks was not ascertained in the past. Similarly, Chroust (2007) found out 1,537 trees per hectare in a 58-year-old oak stand on a control plot, which is a higher number compared to our data from LTP Novačany at the same age (1,090 trees ha^{-1}), which confirms the increased mortality of trees on this subplot due to mass decline in the past.

Table 3. Measurement characteristics of the trees of selective quality (promising and crop trees).

Subplot	Age [year]	Number of trees [tree ha^{-1}]	Basal area [m^2 ha^{-1}]	Basal area % out of the main stand	Merchantable volume [m^3 ha^{-1}]	Merchantable volume % out of the main stand	Mean diameter $d_{1.3}$ [cm] [d_g]	Mean height [m] [h_g]
I–2	54	222	14.9	42.6	230	48.7	29.2	31.2
I–0		214	14.9	28.9	238	32.1	29.8	31.8
P–1	57	173	6.2	20.0	65	24.1	21.4	21.2
P–2		160	6.3	20.0	69	23.7	22.3	21.9
P–3		120	4.7	17.0	49	20.2	22.3	20.8
*N		300	11.6	38.8	121	46.9	22.2	20.9
0c		160	5.8	15.4	63	18.7	21.4	21.7
*0n		387	13.0	33.2	135	37.8	20.7	20.9
N–1	58	124	3.8	14.9	37	16.2	19.7	19.7
N–2		86	2.9	11.9	28	12.4	20.6	19.9
N–0		67	2.6	10.9	26	11.6	22.2	20.0

Note: For explanation see Table 1; *promising trees.

Gubka & Sklenár (2006) discovered 1,960 trees ha^{-1} of northern red oak and 1,920 trees ha^{-1} of durmast oak at the age of 47 years. Much lower numbers of northern red oak at the same age of 47 years, after almost 10 years of intensive tending (after three interventions), were found out by Réh & Réh (1997), i.e. on plots with qualitative crown thinning (according to Schädelin) it was only 417 to 454 trees ha^{-1}, or on plots with the crown thinning with negative selection 323 and 333 trees ha^{-1}. Tokár (1998) found out 1,136 trees ha^{-1} in a 39-year-old pure stand of northern red oak (LTP Ivanka pri Nitre), and 1,360 and 2,404 trees ha^{-1} in a mixed stand with black walnut, which are lower numbers than those found out at LTP Dudince (Štefančík 2011) at the same age.

Réh & Réh (1997) report values of basal area from 26.1 to 36.4 m^2 ha^{-1} in managed plots of the 62-year-old northern red oak stand and 47.2 m^2 ha^{-1} on control plot, which are lower values in comparison with ours even though they were found out in a slightly older stand. The same showed for the case of merchantable volume, when the values of mentioned authors ranged from 295 to 416 m^3 ha^{-1}. On the contrary, our values achieved at the age of 39 years (Štefančík 2011) were almost identical to the data of Tokár (1998), who found out basal area of 30.8 m^2 ha^{-1} and merchantable volume of 310 m^3 ha^{-1} at LTP Ivanka pri Nitre. The values discovered by us at the same age were 31.0 and 29.8 m^2 ha^{-1}, or 304 and 317 m^3 ha^{-1} (Štefančík 2011). It is interesting that the value found out on the control subplot (I–0) in Dudince was even slightly higher compared to the values found out by Gubka & Sklenár (2006), who found out basal area of 33.4 m^2 ha^{-1} and the merchantable volume of 455 m^3 ha^{-1} in an 82-year-old northern red oak stand.

Quantitative production (number of trees, basal area and merchantable volume) reached the highest values in control subplots with northern red oak, which is consistent with the results of other similar experiments (Gubka & Sklenár 2006). Likewise, the values of the average periodic increment on the basal area (i_G) and the merchantable volume (i_{V7b}) found out in the northern red oak stand significantly exceeded those in the durmast oak stand. Tokár (1998) reports increment values of 0.689 m^2 ha^{-1} $year^{-1}$ in pure stand and 0.709 and 0.895 m^2 ha^{-1} $year^{-1}$ in a 39-year-old mixed stand with black walnut. The increment values of the merchantable volume ranged from 7.0 to 10.4 m^3 ha^{-1} $year^{-1}$. Réh & Réh (1997) found out i_G values in the range of 0.865 to 1.099 m^2 ha^{-1} $year^{-1}$ and i_{V7b} values in the range of 10.264 to 18.300 m^3 ha^{-1} $year^{-1}$ in the 62-year-old northern red oak stand, which are values very close to ours. Sandi & Nicolescu (2011) found out i_{V7b} 4.75–6.14 m^3 ha^{-1} $year^{-1}$ in only a 10-year-old stand of northern red oak. Even at a younger age, our values were much higher compared to some European countries (Nicolescu et al. 2020). However, it should be take into account that in the mentioned values were ascertained in much older stands (except for Slovenia). Generally are known about the development of growth and production of other trees and/or of the same growth type (e.g. beech), when growth reaches the highest values in younger and middle age, which is also the case of LTP Dudince (54 years). In addition, this locality was established on former agricultural land, with a high supply of nutrients, which would explain the high values we found.

4.2. Qualitative production

We compared the qualitative production by the proportion of the highest quality trees (promising and crop trees). In the case of control subplots, the highest number of crop trees was on the subplot with northern red oak (214 trees ha^{-1}), on the subplots with durmast oak it was 160 and 67 trees ha^{-1}. With comparing the subplots with tending, the results would clearly confirmed the validation of tending northern red oak stands using the method of crop trees (Nicolescu et al. 2020). This was also shown in our comparative study. In addition to the highest quantitative values (basal area, merchantable volume), an important indicator of stand quality is the proportion of crop trees from the main stand. Also according to this criterion, the results for the northern red oak significantly exceeded the values from stands with durmast oak. Gubka & Sklenár (2006) report 164 trees ha^{-1} of crop trees with a mean diameter $d_{1.3}$ of 37.6 cm and a height of 26.2 m in a northern red oak stand at its age of 82 years. Assuming that an annual diameter increment is only 0.5 cm, which is realistic (Sandi & Nicolescu 2011), at the age of 82 years, the values at the Dudince locality should be higher than those of cited authors, who found out a diameter increment of 0.81 cm per year for potential crop trees. Tokár (1998) states that in a 39-year-old northern red oak stand, the number of promising trees is 328 trees ha^{-1} with their basal area of 9.7 m^2 ha^{-1} and merchantable volume of 103 m^2 ha^{-1}, which are values close to ours at the Dudince locality in the 39-year-old stand (Štefančík 2011). Lower numbers of promising trees (expectant trees by Schädelin) were found out in the 62-year-old northern red oak stand by authors Réh & Réh (1997), who report 128 to 156 trees ha^{-1} with their basal area of 13.4 to 15.1 m^2 ha^{-1} and with merchantable volume of 159 to 164 m^3 ha^{-1}. The number of crop trees in European countries is different, as it depends on the intensity of tending interventions. It ranges from 60–70 (France) up to 400 (Hungary, Czech Republic) (Nicolescu et al. 2020).

The results also confirmed better production capacity of northern red oak crowns compared to durmast oak through crown volume, which was manifested in trees thicker than 27 cm. It can be assumed that it increases even in older age, which was also confirmed by the study of Kupka et al. (2018). These authors also found out greater volume production per spatial unit (crown cover area), which was significantly greater compared to durmast oak.

5. Conclusions

Our comparison of selected quantitative characteristics of the 54-year-old stand of the northern red oak with two stands of durmast oak (57 and 58 years old) in comparable site conditions showed higher values of mean diameter, mean height, basal area and merchantable volume for the northern red oak. Likewise, the values of the mean periodic increment (for volume and basal area) significantly exceeded those we found out in durmast oak stands. Similarly, the higher values of the mentioned quantitative variables were also in the category of trees of selective quality (promising, crop), which are the highest quality trees of the stands. The results confirmed the working hypothesis of higher quantitative production of the northern red oak compared to durmast oak. On the other hand, we are aware that presented results may not have general validity. Such unequivocal results might not be achieved in other locations. Therefore, it is desirable to obtain knowledge from the widest possible experimental material, especially under the conditions of the actual impacts of climate change.

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