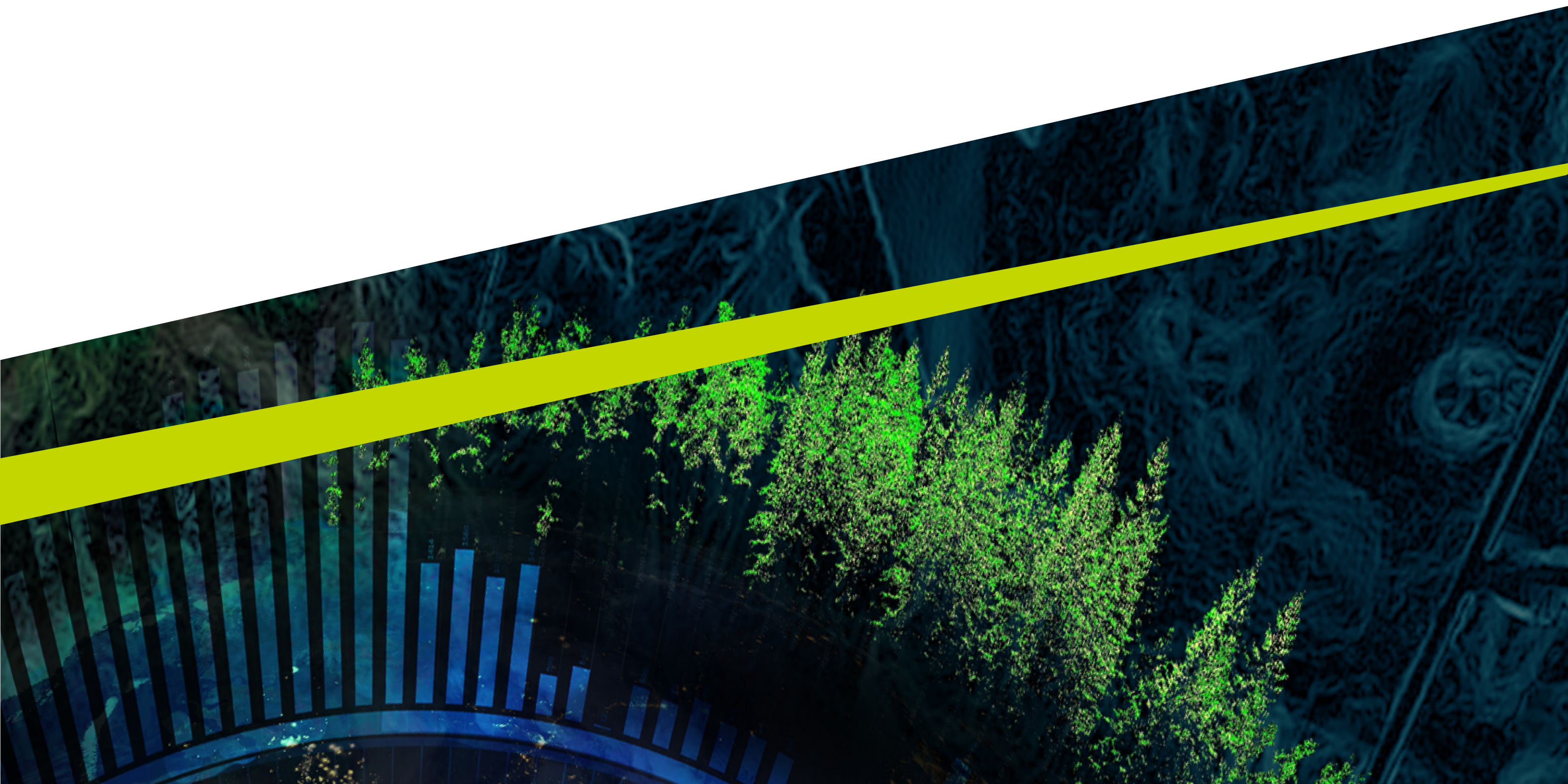
Effects of “classical” vs. “dynamic” silviculture of sessile oak-dominated stands in terms of height, diameter increments and natural mortality

Alexandru-Mihai GOIA



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Abstract

Traditional oak silviculture in Romania is associated with high labor costs and long rotation cycles which are imposed by current norms and regulations. A small-scale R&D project, consisting of a block with four plots of 200 m2, was established in 2001 in a 15-year old sessile oak-dominated stand. The stand was regenerated naturally through the application of group shelterwood cutting. In each plot, ”potential” final crop trees were selected based on vigor-quality-distribution criteria and marked with paint. Silvicultural interventions like cleaning-respacing and thinning of different intensities were performed in three plots (the fourth one was kept as control) in 2001, 2004 and 2009. The effect of stand density on diameter increment was more obvious when considering only the “potential” final crop trees than when all trees were considered. Their quadratic mean diameter (QMD) had reached values close to 20 cm at 35 (30-40) years in the plots with the lowest stand density (STT) and about 15-16 cm for other plots. STT stand with the lowest stand density shows low HDR values having slander trees. The mortality intensity between 2001 and 2019 was highest in the control plot and lowest in STT. Sessile oak showed the highest mortality, followed by Hungarian oak and Turkey oak. In all plots, trees had reached heights corresponding to the hg of ca. 15 m, which is normal for a sessile oak stand of high productivity. The obtained results indicate the ”dynamic”, crop tree silviculture with the active selection of the most valuable individuals as ”potential” final crop trees at the end of thicket stage as being a possible solution for managing sessile oak young and medium-aged stands. Nonetheless, these trees should be managed by subsequent crown thinning, in order to produce timber with as uniform as possible radial increments of 2-3 mm, as is requested by veneer and high-quality saw log buyers.

Key words: sessile oak, cleaning-respacing, thinning, stand silviculture, crop tree silviculture, mortality, growth, Romania.

Popular Science Abstract

Silvicultura tradițională a Cvercineelor în Romania este adesea corelată cu cicluri de rotație de lungă durată si costuri ridicate, ambele fiind impuse de normele și regulamentele în vigoare. În 2001, un experiment cu rol de cercetare și demonstrare a fost instalat într-un arboret de Stejar pedunculat (*Quercus petraea*) în vârstă de 15 ani, regenerat natural în urma tăierilor progresive. Experimentul a constat în amplasarea în teren a unui bloc compus din patru piețe de probă a câte 200 m^2 fiecare, precum și în selectarea și vopsirea a câte șapte arbori de viitor în fiecare piață de probă. Una dintre cele patru piețe de probă a fost considerată drept piață de control (în cadrul ei nu s-a realizat nici o intervenție asupra arborilor) iar în celelalte trei au fost aplicate tratamente precum curățiri și rărituri, intensitatea intervenției variind în funcție de piața de probă. Impactul densității asupra creșterii în diametru a fost mai vizibil în cazul arborilor de viitor. Media lor pătratică a înregistrat valori apropiate de 20 cm la vârsta de 35 (30-40) ani în piața de probă cu cea mai mică densitate, pe când în celelalte piețe de probă valoarea acesteia a fost de aproximativ 15-16 cm. Totodată, rata mortalității a fost cea mai ridicată în suprafața de probă păstrată drept piață de control și scăzută în restul arboretului cu densitate mai redusă. Rezultatele obținute indică faptul că modelul ”dinamic”, respective, silvicultura orientată în jurul arborelui de viitor și selecția activă a arborilor potențiali de viitor încă din faza de nuieliș-prăjiniș poate fi utilizată în gospodărirea arboretelor tinere de Stejar pedunculat (*Quercus petraea).*

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1. Introduction

Oaks (*Quercus* spp.) are the most important broadleaved tree species in Europe (cover ca. 21 million ha), of which pedunculate oak (*Q. robur* L.) and sessile oak (*Q. petraea* (Matt.) Liebl.) are the most common, occurring widely across most of Europe.

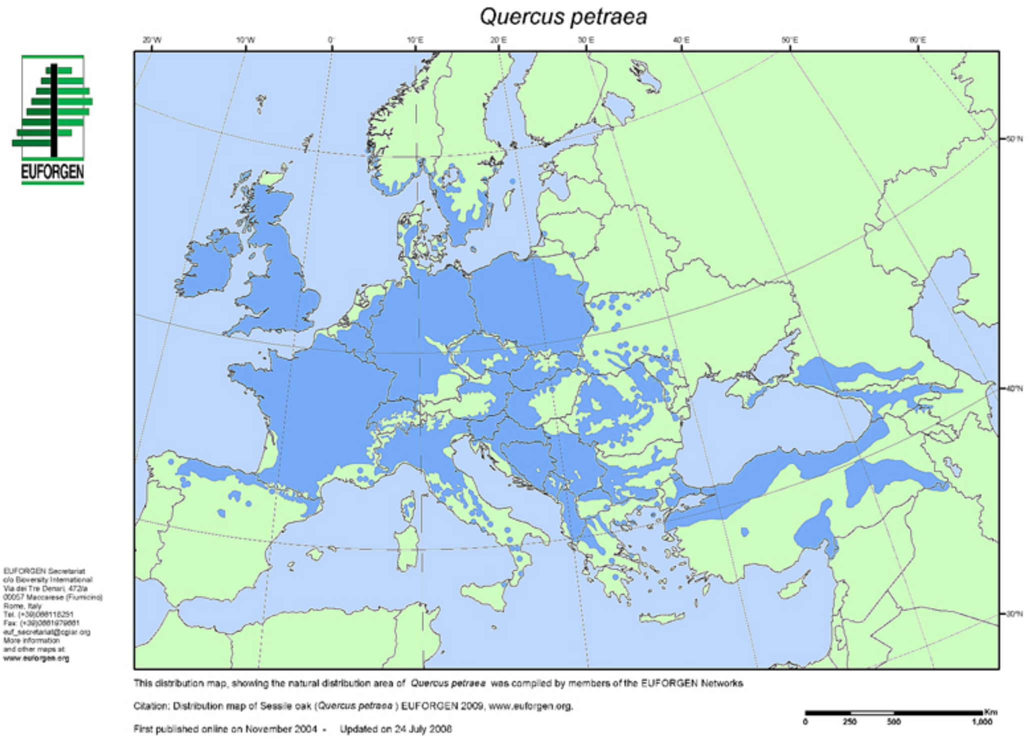


Figure 1 Natural distribution of sessile oak (Quercus petraea)(EUFORGEN, 2020).

Sessile oak can be found in the lowlands of Europe from the Atlantic coast of France, Northern Spain, Portugal and Britain in the west, to the Ural Mountains in the east, reaching its northern limits in northern Scotland and southern Scandinavia, while the southern limits extend to Italy, Greece, northern Spain and Portugal. The species essentially overlaps pedunculate oak, but it is restricted to Central and Western Europe, without extending eastwards into Russia (Figure 1). What is more, to the north, it is present only where the climate is influenced by maritime conditions (Attocchi, 2015).

1.1. Sessile oak in Romania

In Romania, sessile oak is the dominant oak species. It covers 588 161 ha (over 8 per cent of national forest land, and over 52% of all *Quercus* species), it has a mean volume of 284 m^3 ha^{-1} and produces 7.3 m^3 ha^{-1} yr^{-1} on average (Marin, 2015). It grows in both pure and mixed stands with other oak species (e.g. pedunculate oak, Turkey oak (*Q. cerris* L.), Hungarian oak (*Quercus frainetto* Ten.), European beech (*Fagus sylvatica* L.), hornbeam (*Carpinus betulus* L.), maples *Acer* spp., common ash (*Fraxinus excelsior* L.), etc.(Negulescu and Săvulescu, 1957, Stănescu, 1979)
Mature Sessile oak is a light-demanding species, but can resist more shade than pedunculate oak, especially in young ages (Ciumac, 1965, Haralamb, 1967, Petrescu, 1971). Therefore, it is regenerated under group shelterwood systems, with gaps having the size of 1.5 x mean height, and with a regeneration period recommended to be between 5 to 7 years (Ciumac, 1965, Haralamb, 1967). As a consequence, the resulted regeneration encounters a high intensity natural mortality in the first years i.e. 40-50% of the initial number of seedlings in the second year (Purcelean and Ciumac, 1965). However, the stand density can be high, up to 30,000 stems ha^{-1}, at the end of sapling and beginning of thicket stage (Dămăceanu, 1984). Such dense, uniform and single-layered stands, predominantly pure, with tall but slim individuals, can be prone to snow bending (Petrescu, 1971).

Sessile oak is a slow-grower in the first decade (it grows in height 10-20 cm yr^{-1} during this period), when the growth is concentrated in the root system. The height growth activates afterwards and reaches up to 50 cm yr^{-1} between age 10-25 years (Negulescu and Săvulescu, 1957, Haralamb, 1967).

The silvicultural model of Romanian sessile oak stands, imposed by the current Technical norms (Anonymous, 2000a) is mostly a stand silviculture consisting of:

- Cleaning-respacing, started when dominant height (H_{dom}) is 8-10 m (age 15-20 years). This treatment is a negative selection (removal of suppressed and poorly formed trees without considering the growth of remaining ones), with moderate intensity, keeping a canopy cover of minimum 80% (75% in stands with rich understory).

- Thinning starts when H_{dom} is 12-13 m (age 25-30 years). It is intermediate (from above and from below) and acts as a positive selection (competing trees are removed, to maximize the growth of the best ones (Kerr and Haufe, 2011). The intensity of thinning (per cent of standing volume) ranges between 14% (age 21-30 years) and 6% (age 71-80 years). At and age of 71-80 years, thinning halts as required by the Technical norms. Canopy cover after thinning should be at least 80%.

In valuable sessile oak stands, the same norms recommend selecting and paint 200-300 ‘‘candidate‘‘ final crop trees ha^{-1} at an age of 25-30 years. The selection is based on vitality, quality and spatial distribution and the aim is to reach a stand density of 90-100 trees ha^{-1} final crop trees at rotation age. However, under the current Technical norms, with moderate-low intensity interventions halting at early ages, the target density is difficult to reach, and sessile oak stands often have 250-400 trees ha^{-1} at rotation age. This density is significantly higher than the one recommended in other European countries: maximum 100 trees ha^{-1}, e.g. 70-100 in Belgium (Bary-Lenger and Nebout, 1993); 80-100 trees ha^{-1} in Austria (Hochbichler, 1993) and Germany (Kenk, 1984); 100 trees ha^{-1} in Ireland (Joyce et al., 1998), but decreasing to 60-70 trees ha^{-1} in France (Sevrin, 1997).

The rotation age in sessile oak stands for wood production in Romania is dependent on target wood assortment and ranges between 120 and 140 years for saw logs and between 160 and 200 years for veneer logs (Anonymous, 2000b).

It is clear that oak possesses a substantial economic potential for the landowner when managed for high-quality wood production. However, the traditional way of growing oaks is associated with high labor costs and a long rotation cycle. This has led to a search for new oak silviculture methods to optimize the production of high-quality timber in a cost-efficient manner.

1.2. Aims of the study

The aim of the study was to compare two types of Oak silviculture - stand silviculture vs. single-tree oriented silviculture. The latter option including interventions focusing around potential crop trees. This analysis consists of a comparison of treatments effects in terms of diameter growth, height to diameter ratio (slenderness), natural mortality and amount of epicormic branches.

2. Materials and Methods

In this thesis, data from a Research and Demonstration (R&D) experiment located in Romania, Dâmbovița County in a state-owned forest was studied.

2.1. Site description

The research work was carried out in sub-compartment 71E (44°50'42.91"N 25°21'02.36"E), part of Working Circle IV Râncăciov, Valea Mare Forest District, Dâmbovița County Branch of National Forest Administration-ROMSILVA (Figure 2).

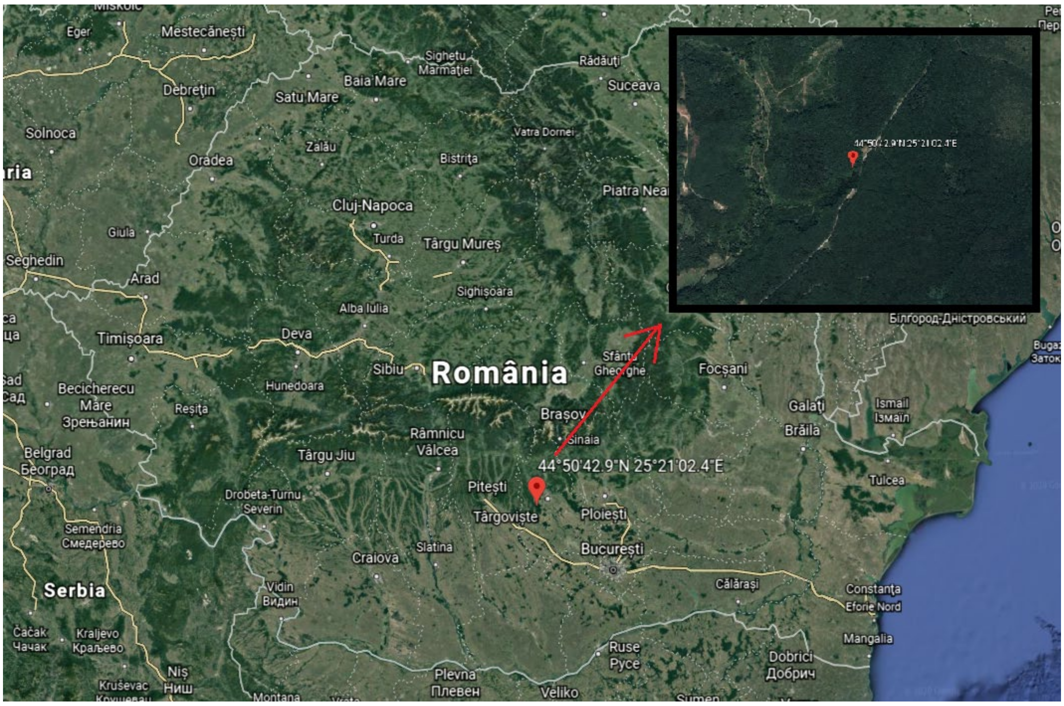


Figure 2 Sub-compartment 71E, Valea Mare Forest District (Google-Earth, 2020)

The main characteristics of this sub-compartment are as follows:

- Site: Area: 6.7 ha; Elevation: 290 m; plateau; Soil: luvisol, of high fertility for sessile oak stands; Ground flora: Carex pilosa. Climate: D.f.b.x. type;

annual mean temperature 9.9°C, annual mean precipitation 688 mm, aridity (de Martonne) index 35.

- Stand (2019): Species composition: over 90% sessile oak with scattered individuals of Hungarian oak, Turkey oak, hornbeam, European beech, field maple Acer campestre L., etc. Mean age 35 years (range 30-40 years). The stand was naturally regenerated by the application of group shelterwood cuttings (stand naturally regenerated by seed). Production class: II. Rotation age: 130 years; production target: sawn timber with diameter at breast height of at least 48 cm.

2.2. Field work, experimental design and treatments description

The fieldwork has started in 2001 and consisted of the following interventions and works:

In 2001 the R&D block of 1,500 m^2 (30 x 50 m) was established, and a plot of 200 m^2 (10 x 20 m) was install in each corner of the block (Figure 3).

In all plots, potential final crop trees (7 trees per plot = 350 trees ha^{-1}) were selected and painted, based on the vitality, quality and spatial distribution. In plot ST, all potential final crop trees were of sessile oak, in the control plot two out of seven trees were Hungarian oak, and in plots STT and TFB two out of seven trees were Turkey oak. All the other potential final crop trees (five individuals per plot) in these three plots were sessile oak.

The data was collected as follows:

In 2001, 2004, 2009 and 2019 the diameter at breast height (dbh) was measured for all trees using a Haglöf caliper with a precision of 0.1 cm.

The height was measured in the years of interventions (2001, 2004, 2009) and in 2015 using a Romanian hypsometer (precision 10 cm). Sample trees were selected for a good representativity of each diameter class hence, heights were measured for small to intermediate diameter trees as well as for the big trees.

In addition, an assessment of presence of epicormic branches (length, diameter at insertion point, height to lowest epicormic) was made in 2017 in all plots.

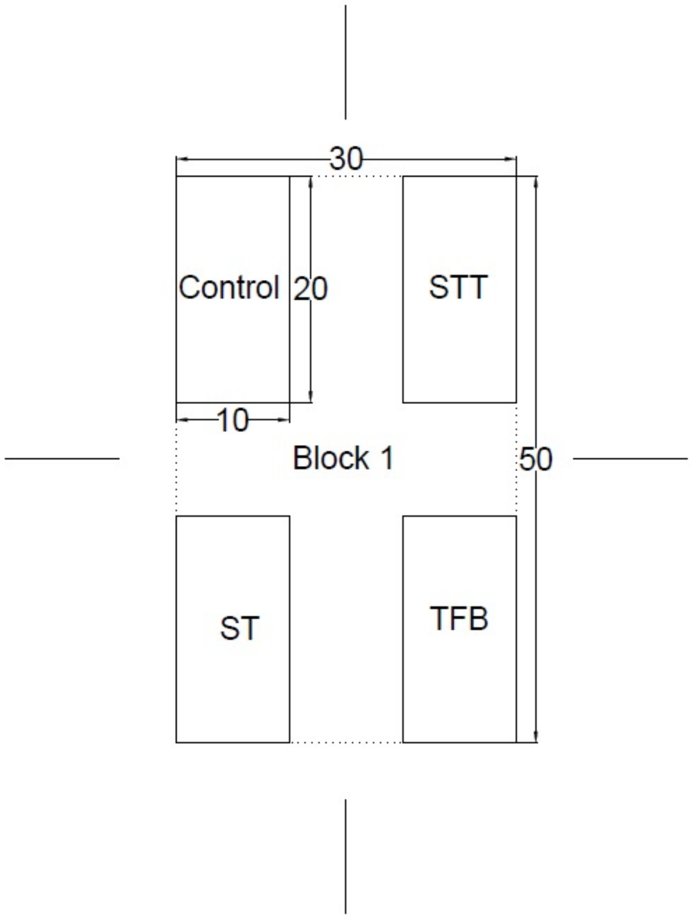
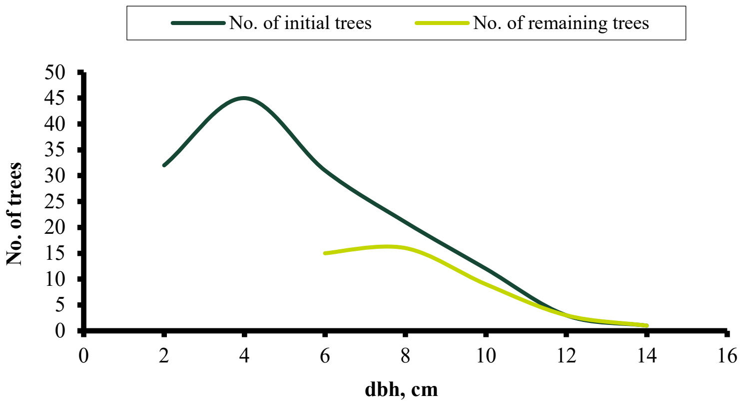


Figure 3 Experimental design and treatment distribution

2.2.1. Treatments description

The four treatments are as follows:
STT - Single tree thinning (“dynamic silviculture”)
TFB - Thinning from Below
ST - Stand thinning (“classical silviculture”)
Control - Control plot where no intervention was made

The tree species where coded for a better use of space as follows :
Sessile oak-**SOAK**,
Turkey oak-**TOAK**,
Hungarian oak-**HOAK**



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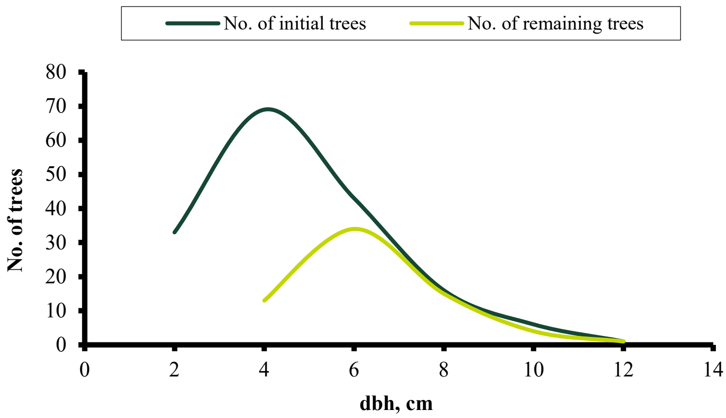

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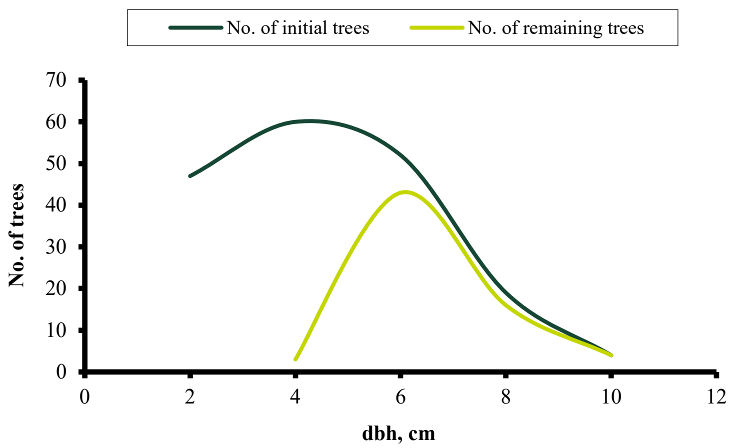

c)

Figure 4 Typical intervention (cleaning-respacing) from below performed in plots a)STT(Single tree thinning), b) TFB(thinning from below), c) ST(Stand thinning) in 2001

As the initial stand density (between 7,250 trees ha^{-1} in plot STT and 9,100 trees ha-1 in plot TFB), as well as stocking (range 17.55 m^2 ha^{-1} in plot ST - 20.65 m^2

ha^{-1} in plot STT) were very high in 2001 (Figure 4), and no silvicultural interventions have been performed since the stand establishment, the intensity of first cleaning-respacing (2001) in all plots (Figure 4 and Table 1) excepting the control plot was very high, 31-40% for basal area and 58-70% for number of trees. Because the range of diameters was very wide in these plots this intervention was from below as is indicated by the difference in per cent removal of basal area and stem number. Coefficient of variation of diameters before intervention was ranging between 40-50% and was reduced to 20-25% in the thinned plots.

After the interventions performed in 2001, a further cutting was done in 2004 in plot TFB, the intervention consisted in a cleaning-respacing where again suppressed trees were removed (Table 1).

Table 1 Types and intensities of interventions performed in plots STT, TFB and ST in 2001, 2004, and 2009

Treatment	Intervention performed in ...								
	2001			2004			2009		
	I_N* %	I_G** %	Type of intervention	I_N %	I_G %	Type of intervention	I_N %	I_G %	Type of intervention
STT	69.7	39.8	*From below*	-	-	-	41.9	39.3	*Intermediate*
TFB	57.9	31.0	*From below*	14.9	8.5	*From below*	30.4	21.0	*From below*
ST	63.7	34.5	*From below*	-	-	-	28.8	21.6	*Intermediate (mostly from below)*

IN* = intensity by number of trees; IG** = intensity by basal area

The third intervention was done in 2009 and it consisted in thinning of different intensities in all thinned plots. In STT the thinning type was intermediate with high intensity both in terms of number of trees (41.9 %) as well as in basal area (39.3 %). In TFB the type of intervention was from below and as it can be seen in Table 1, it had a moderate intensity. The same moderate intensity of thinning as in the previous plot was used in ST plot but its type was intermediate, mostly from below.

The area outside the block was thinned and kept with the same density as the one from the closest plot (Figure 3) and between the plots inside the block, same treatment as in each plot was applied on a distance of 5 m from the plot border to the centre of the block.

Table 2 QMD of initial trees, extracted trees and residual trees in cleaning-respacing and thinning carried out in plots 1-3 in 2001, 2004, and 2009

Plot	QMD in..., cm								
	2001			2004			2009		
	Initial trees	Extracted trees	Residual trees	Initial trees	Extracted trees	Residual trees	Initial trees	Extracted trees	Residual trees
STT	6.0	4.6	8.5	9.4	-	9.4	11.6	11.2	11.8
TFB	5.3	3.9	6.8	7.5	5.7	7.8	9.7	7.6	10.4
ST	5.1	3.8	6.9	7.5	-	7.5	9.2	7.9	9.7

In 2001 and 2004, as the QMD of extracted trees is much lower than the one of initial trees, the cleaning-respacing was a negative selection, acting from below. In 2009, the only thinning from below was carried out in TFB, while its character approached an intermediate intervention (or détourage) in the other plots (Table 2).

2.2.2. Stand development

As mentioned before, the stand density at the beginning of interventions (2001) in all plots was extremely high, ranging between 7 250-9 100 trees ha^{-1}. Under these conditions, the interventions performed in 2001 (plots “STT, TFB, ST”), 2004 (plot TFB), and 2009 (plots “STT, TFB, ST”), combined with the natural mortality of trees reduced the stand density to values ranging between 1 250-1 750 trees ha^{-1} (Figure 5).

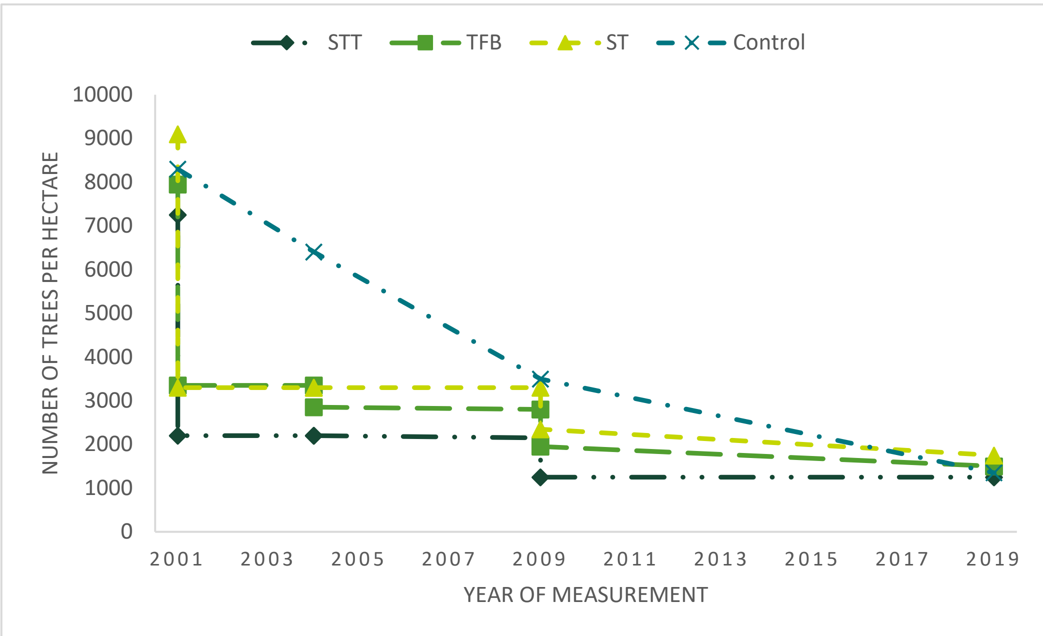

Figure 5 Evolution of stand density in all plots between 2001 and 2019

This reduction in stand density was due primarily to the three silvicultural interventions (2001, 2004, and 2009) performed in plots STT,TFB and ST, where the natural mortality over the 2001-2019 period counted for less than 20%. On the contrary, the only source of reduction of stand density in the Control plot in the same period was natural mortality.

Stocking in terms of basal area in these four plots has been successively increased because of growth between interventions and decreased because of silvicultural interventions and natural mortality (Figure 6).

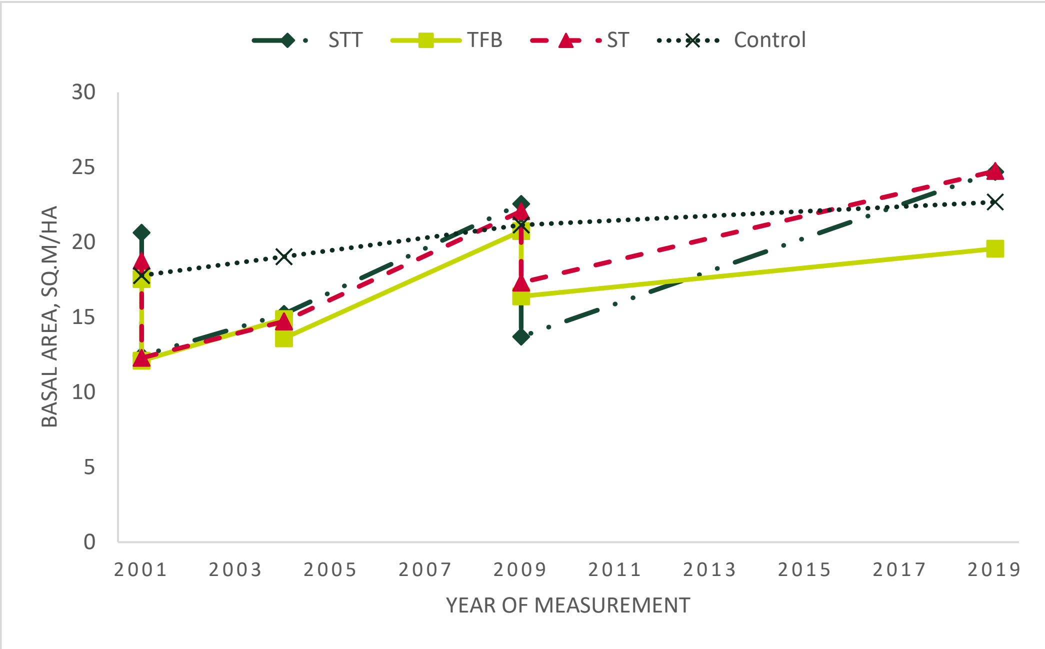

Figure 6 Evolution of stocking (basal area) in all plots between 2001 and 2019

Starting around 12 m^2 ha^{-1} in all plots after the first intervention in 2001, basal area has increased up to rather similar values (21.76 m^2 ha^{-1} - 25.63 m^2 ha^{-1}) in 2019. However, the evolution of stocking between the last intervention (2009) and 2019 showed a very high variability. The increase of basal area ranges between 0.61 m^2 ha^{-1} (2.88%) in the control plot (with the highest stand density of 3,500 trees ha^{-1} and a mortality of 61.43%) and 11.00 m^2 ha^{-1} (80.29%) in STT plot (with the lowest stand density of 1,250 trees ha^{-1} and no mortality). In the other plots, basal area has increased 6.60 m^2 ha^{-1} (38.13%) in ST and 9.24 m^2 ha^{-1} (56.38%) in TFB (Figure 6).

2.3. Statistical analysis

Normal distribution of data was checked using Shapiro Wilk test because it has the ability to detect weather a sample comes from a non-normal distribution. In addition, QQ-plots of the data were used to graphically analyze the distribution. As the results of the test show that the data is not normally distributed in most of the plots, Wilcoxon test was used to assess the differences between treatments in terms of diameters of potential final crop trees.

Generally, relationship between height and diameter of a tree is nonlinear regression and height curve increases more rapidly in earlier stages than in later stages (Rp et al., 2016). As it can be observed in Figure 7 our data show a significant nonlinear pattern. Analyzing various previously published studies on Height/Diameter modelling, the Näslund (1936) function was choose and used to estimate the height – diameter curve and to predict the missing values for tree heights.

$$h_{ij} = 1.3 + \left(\frac{DBH_{ij}}{b_1 + b_2 DBH_{ij}}\right)^3 + \boldsymbol{\varepsilon}_{ij}$$

where:

h_{ij} – height measurement for tree j (j = 1, …, m) on sample plot i (i = 1, …, n),

1.3 – added to avoid the prediction of zero height when DBH approaches zero,

DBH_{ij} – diameter measurement for tree j (j = 1, …, m) on sample plot i (i = 1, …, n),

b1, b2 – parameters to be estimated,

$\boldsymbol{\varepsilon}_{ij}$ – residual error.

This bi-parametric model is based on the growth theory (the faster increase of height in the earlier stage and slower in the later stage) and it is suitable both for single canopy-layered stands and for multi-layered stands. This model has a pronounced flexibility, thus, it provide good fits for height-diameter data for a number of tree species (Mehtätalo et al., 2015). The Näslund (1936) function was fitted to the dataset as a simple mixed-effects model using package "*lmfor*" of R-environment.

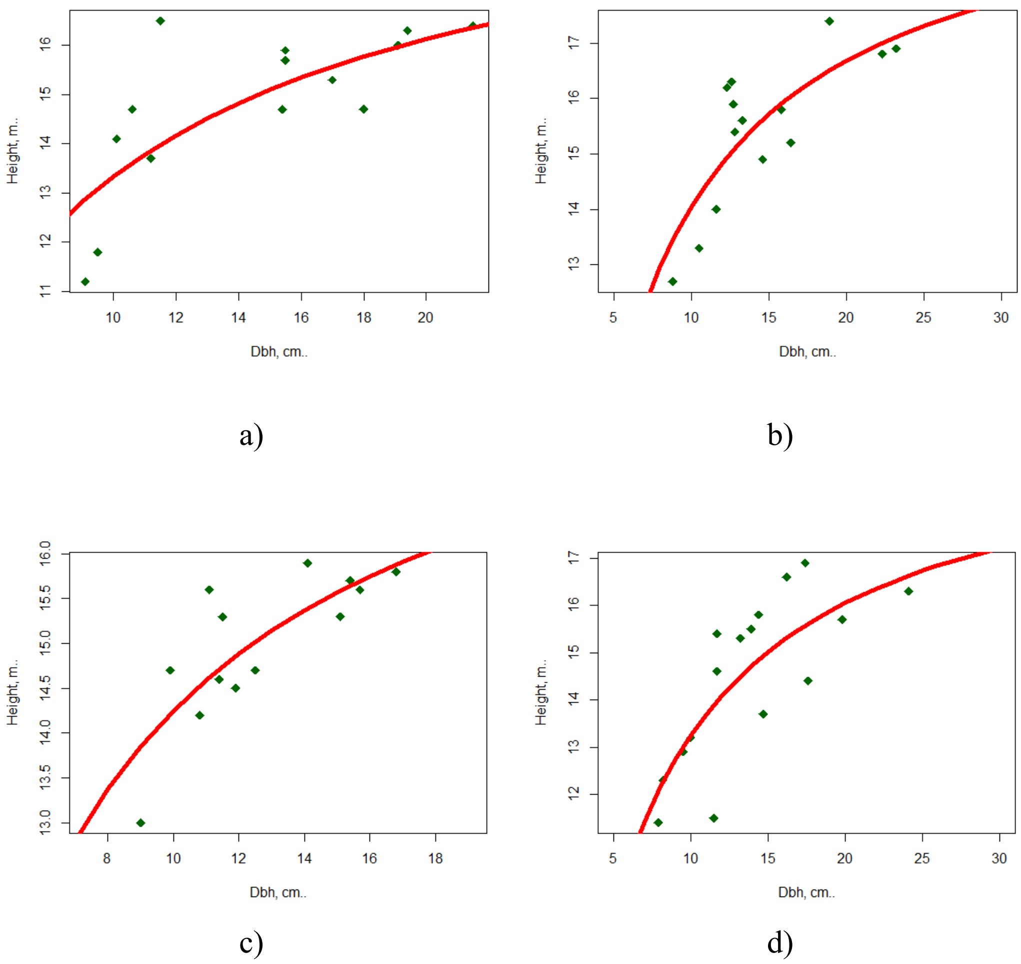

Figure 7 Height diameter curve for year 2015: a) STT, b)TFB, c)ST and d)Control

The predicted height values were used to calculate HDR (Height: diameter Ratio). In order to have a better view on the relationship between height and diameter, a regression model was made on all treatments using HDR as dependent variable and Dbh (measured in 2015) as explanatory variable.

lm(HDR~DBH+STT+TFB+ST+DBH*STT+DBH*TFB+DBH*ST)

Table 3 Example of the variables and dummies used in the regression model

Plot	Dbh_2015	HDR	STT	TFB	ST
STT	13.2	112	1	0	0
TFB	12.3	122	0	1	0
ST	11.6	128	0	0	1

Three dummies (Table 3) were created and included in the regression, one for each thinning treatment.

3. Results

3.1. Effects of silvicultural interventions and natural mortality on ”potential” final crop trees

3.1.1. Dbh of ”potential” final crop trees

The effect of stand density (treatments) on dbh increment are more obvious when considering only the potential final crop trees. In order to compare the treatments effects upon the diameter of the future crop trees the nonparametric Wilcoxon test was used.

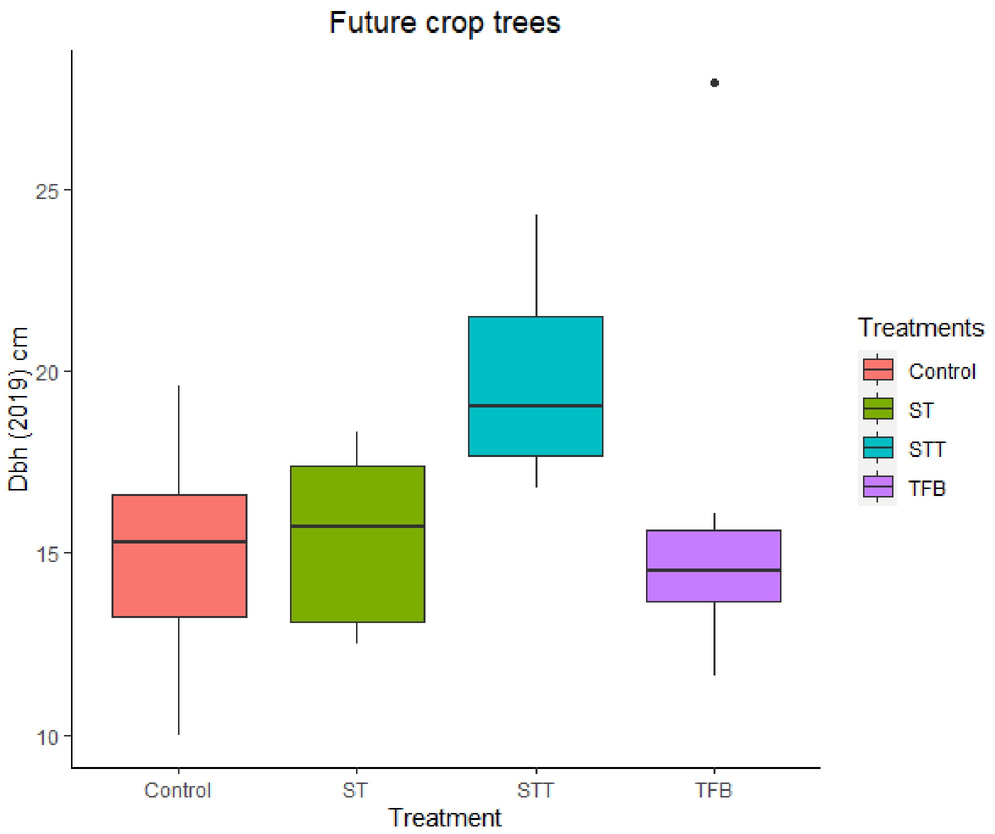

Figure 8 Boxplot of future crop trees dbh values measured in 2019.

The results of the test show that, when comparing the diameters of future crop trees from treatment STT with the diameter values of future crop trees affected by the other treatments a significant difference between their median values is found, P value being **0.03125** (less than significance level α = 0.05(Table 3).

Table 4 Pairwise comparison between treatments using Wilcoxon nonparametric test on dbh values measured in 2019.

Groups		P value
STT	ST	**0.03125**
STT	Control	**0.03125**
TFB	Control	**0.6875**
ST	Control	**0.9375**

Thus, dbh of future trees from treatment STT is significantly higher than the dbh of future trees from all other treatments whereas no significant difference occurred between the values of the trees from the other treatments (TFB, ST and Control).

3.1.2. Assessment of the effect of Dbh on Height: Diameter ratio (HDR)

Having into consideration the hypothesis that dense stands lead to low HDR a regression to test this assumption and to observe the Dbh`s influence on HDR was made.

Table 5 Regression results. Dependent variable= HDR; Predictors=Dbh2015 and 1 dummy for each treatment

	Estimate	Std. Error	t value	p
Intercept	184.7985	4.426	41.753	2E-16
Dbh_2015	-5.5087	0.3079	-17.893	2.39E-13
STT	-24.5672	6.9315	-3.544	0.00217
TFB	-6.3372	5.2681	-1.203	0.24378
ST	20.5417	6.6283	3.099	0.00591
Dbh_2015:STT	1.5248	0.43	3.546	0.00216
Dbh_2015:TFB	0.8585	0.3648	2.354	0.02951
Dbh_2015:ST	-1.2061	0.4658	-2.589	0.01799

Considering that p value = 0 (< α =0.05) we can observe in Table 4 that the variables STT (p=0.0021) and ST (0.0059) are statistically significant for the model while treatment TFB is not considered to be statistically significant (p=0.24).

In the plot STT, it can be observed that if the diameter increases with 1 unit, HDR will decreases in average with 24.56 units this is due to lower intercept and higher slope. On the other hand, in plot ST for an increase of 1 unit in dbh, HDR will increase with 20.54 units.

Comparing the results, the influence of the treatments upon the HDR values is quite heterogeneous. The coefficient of regression for TFB indicates that there is no significant difference between the control plot and this treatment in terms of heights and dbh`s effect upon HDR of future crop trees. As it was showed above, when it comes to the other two treatments (STT and ST), in both cases the dbh of the trees has significant influence upon HDR.

3.2. Effects of silvicultural interventions and natural mortality on different stand parameters

3.2.1. Natural mortality and evolution of species composition

The natural mortality of trees (sessile oak SOAK, Turkey oak TOAK, and Hungarian oak HOAK) between 2001-2019 was very variable (Table 4). The lowest natural mortality was registered in STT treatment, with the lowest stand density after the intervention carried out in 2001 (2,200 tree ha^{-1}), while control plot, with the highest stand density in 2001 (8,300 trees ha^{-1}) showed the highest natural mortality. The species most affected by natural mortality was sessile oak, with a share of dead trees between 75.97% (control) and 100.00% (STT and ST) in 2001-2019. Hungarian oak contributed secondly to natural mortality in Control plot (24.03%), while Turkey oak contributed with 10% of dead trees in TFB. All of them are light-demanding species, and all dead trees were part of low canopy, belonging to crown classes IV and V.

Table 6 Natural mortality of trees between 2001 and 2019 and in the 2009-2019 period

Treatment	Residual number of trees in 2001	Natural mortality 2001-2019, %	Share of natural mortality in 2001-2019, %		
			SOAK	TOAK	HOAK
STT	2,200	2%	100%		
TFB	3,350	15%	90%	10%	
ST	3,300	18%	100%		
Control	8.300	84%	76%		24%

In contrast, no trees of European beech (shade tolerant) or hornbeam (with intermediate shade tolerance) have died during the same periods. For all treatments except ST sessile oak encountered a decline while the other tree species encountered a relative increase in their basal area.

3.2.2. Effects of silvicultural interventions and natural mortality on height of all trees

The increase of this parameter of all trees in all plots between 2001-2015 ranged between 5.3-9.1 m (Table 6). The highest increase (both relative and absolute here) in h_g was found in the control plot.

Table 7 Evolution of height corresponding to the quadratic mean diameter (hg) of all trees in all plots between 2001-2015 (last year of height measurements)

Treatment	h_g in..., m				Increment of h_g between 2001 and 2015	
	2001	2004	2009	2015	m	%
STT	9.5	10.1	12.0	14.6	5.2	54%
TFB	9.0	9.4	11.8	14.7	5.7	62%
ST	8.9	9.7	11.9	14.7	5.8	64%
Control	5.6	7.6	10.6	13.5	7.9	141%

However, hg-values for 2015 were not different between the treatments, indicating that treatments had no significant impact on height-development.

3.3. Occurrence of epicormic branches

The effect of different types of intervention on individual trees was also assessed in terms of occurrence of epicormic branches, a major threat in oaks (more on pedunculate than on sessile) to produce top-quality wood for A-class lumber, veneer and solid furniture. In all plots, the share of trees with epicormics in 2017 ranged between 20%-40%. Sessile oak and Hungarian oak trees were the most affected. However, the potential final crop trees, with the largest diameters, heights and crowns, had been least affected with maximum one tree per plot (Table 9).

Table 8 Occurrence of epicormic branches

Treatment	Total number of trees	No. and % of trees with epicormics	Of which		Number of "potential final crop trees	Of which with epicormics	
			Sessile oak	Others (HOAK, EB, HO)		No.	%
STT	25	10/40	7	3	7	1	14
TFB	35	2/26	9	-	7	-	-
ST	41	8/20	7	1	7	1	14
Control	33	12.36	4	8	6	1	17

HO = Hungarian oak, EB = European beech, HO = hornbeam

4. Discussions

In the young sessile oak thicket, stand density and stocking were very high (N = 7,250-9,100 trees ha^{-1}; G = 17.55-20.65 m^2 ha^{-1}) in 2001, so there was a clear need for cleaning-respacing. Considering the high variability of diameters and qualities, this intervention was a negative selection, removing the smaller and badly formed trees, with heavy intensity. The intervention in 2009 was not as heavy as the one in 2001 (intensity 28-41% by N and 21-39% by G), and the stand density was reduced to 1,250-2,350 trees ha^{-1}. The minimum stand density in 2009 is similar to the one recommended in countries like France (1,100-1,200 trees ha^{-1} - (Sardin, 2008); (Sardin and Mothe, 2010)), Belgium (ca. 1,200 trees ha^{-1} - (Baar, 2008)) or Ireland (1,000-1,300 trees ha^{-1} (Joyce et al., 1998)) but much lower than the one proposed in Romania (2,000-4,000 trees ha^{-1} - (Ciumac, 1975); 2,100-2,400 trees ha^{-1} - (Anonymous, 2000a)) at the same age. Stocking after the interventions performed in 2009 (13-17 m^2 ha^{-1}) is similar to the one recommended in France (14.2 m^2 ha^{-1} - (Jarret, 2004); 14.7 m^2 ha^{-1} in "dynamic" silviculture and 16.8 m^2 ha^{-1} in "classical" silviculture (Sardin, 2008)) and Belgium (14-18 m^2 ha^{-1} - (Balleux, 2005)) under similar stand conditions.

When it comes to diameter growth the diameter of future crop trees was analyzed and compered first. In this respect the results show that future crop trees grow better in the low density stands (treatment STT) while the future crop trees from the other two treatments (TFB and ST) had similar diameter growths as those from the Control plot. As Hein and Dhôte (2006) also mention in their study, a strong reduction of stand density is necessary in order to obtain a significant dbh growth.
In order to assess the treatments effect on the stand stability, Height: Diameter ratio (HDR) was calculated and a regression model having HDR as dependent variable and dbh as predictor variable was made. The results show that for two of the treatments Dbh has a significant effect on HDR. We can observe that in the plot with the lowest stand density (treatment STT) an increase of dbh value results in a decrease of HDR, (slender trees). On the other hand, in the plot where stand density was highest in 2015 (treatment ST) an increase in dbh leads to an increase in HDR as well and higher overall HDR values. As Wonn and O'Hara (2001) write in their article high values of HDR show that either trees have grown in an extremely open stand (which is not the case in this thesis) where no significant competition occurs

or in a crowded stand with mutual support from neighbouring trees. They (Wonn and O'Hara, 2001) have also said that smaller values of HDR indicate longer crown length, higher crown projection area, better developed root system, lower position of the center of gravity, and higher stability of the trees.

The mortality process, affecting mostly trees in lower crown classes (IV and V), confirms the low shade tolerance of all oak species, with sessile oak being the most affected. Its higher needs for light conduct even to the change of species composition in favor of more shade tolerant Hungarian oak (Negulescu and Săvulescu, 1957, Stănescu, 1979), as in case of Control (control). Nonetheless, natural mortality has not affected at all the shade-tolerant (European beech) or intermediate shade-tolerant (hornbeam) species, their share in basal area increasing slightly, with positive effects on biodiversity.

When it comes to the height corresponding to QMD (hg), similar growth was found in all plots until 2015. Similar studies like Shifley (2004) have found that height of dominant trees is less affected by stand density. This value characterizes fully the high growing potential of local site conditions, as the stand belongs to the production class II (h_g 14.1 m at 35 years of age - (Giurgiu and Drăghiciu, 2004). The basal area, with a series of increases and decreases due to silvicultural interventions, natural mortality and diameter increment reached values over 21 m^2 ha^{-1} in 2019. This is higher than the values considered as “critical” (14-18 m^2 ha^{-1}) (Balleux, 2005) in order to avoid loss in diameter increment of crop trees.

Sessile oak is considered a species particularly prone to the occurrence of epicormic branches (Colin et al., 2010); this represents a major defect reducing the quality class of saw logs. In the EU standards, the quality of sessile oak saw logs is reduced from A to B or even C, if the knots are larger than 15 mm in diameter (Baylot and Vautherin, 1992, Anonymous, 1997). In the present project, silvicultural interventions have not had a major detrimental effect on the production of epicormic branches. This is especially true in case of potential final crop trees, with large crowns, showing a good vitality and growing vigorously, which are less prone to the occurrence of epicormics (Jarret, 1996, Joyce et al., 1998, Colin et al., 2010, Sevrin, 1997). If epicormics occurs on the most vigorous trees, it is a sign that the dominant story is too dense and crown thinning should be applied (Boppe, 1889).

The results of this study show that, in the “dynamic” silviculture, the positive selection (and painting) of potential final crop trees, at the end of thicket stage at a mean height of 6-8 m, followed by a heavy intervention around their crowns, as proposed in other European countries such as France (Allegrini, 2010, Deleuze and Renaud, 2010) and Belgium (Baar, 2008), is a feasible option. The number of such trees (ca. 300 individuals ha-1), selected and painted based on the vigor-quality-spacing criteria, should be 2-3 (4) times the number of trees which will presumably form the final stand at the rotation age (final crop trees) (Petrescu, 1971, Kerr and Evans, 1993, Colin et al., 2010). By selecting and painting them, therefore making such trees more visible and easy to locate, the further tree marking for thinning is facilitated, and both foresters and loggers are helped in their efforts to protect the most valuable trees and produce high-quality, healthy, and large trees (Lanier, 1979).

Noticeably, the “potential” final crop trees should be favored by further interventions with crown thinning, removing the most aggressive competitors at crown level, in order to provide the final crop trees, selected as early as the first or second thinning. Consequently, the crown development and correlated diameter increment are increased (Dobrovolný and MacHáček, 2012), confirming the fact that, in young and medium-aged oak stands, the bigger trees grow usually much faster than the smaller ones (Gadow and Hui, 1998). The application of crown thinning in oak stands is not a new concept. It was advocated by Broilliard (1881) and used in French forests ever since. In Romania, such thinning in sessile oak stands was proposed by Ciumac (1969) after stating that all final crop trees belong to the upper story so they need to be released from competition, but never formalized and used in practice.

5. Conclusions

All the applied treatments show similar effects upon trees at stand level up to the last measurement. Considering all trees, no significant differences between treatments in terms of both diameters increment as well as heights occurred. The only difference between the treatments was encountered when assessing the natural mortality. In this respect, the plot with the lowest stand density had the lowest natural mortality whereas the densest plot had highest natural mortality. Moreover, in what regards the trees quality, there was no negative effect of the treatments on epicormic branches.

The potential final crop trees where the “dynamic” silviculture treatment (STT) was used show greater diameter growth and better stand stability (lower HDR values) than future crop trees in the other three treatments. Future crop-trees where the “classical” silviculture treatment (ST) was applied had similar diameter growth as crop-trees in the Control plot.

This study`s results indicate that a strong reduction in competition is needed in order to have a significant effect on potential final crop-trees. Hence, in order to obtain a positive development of diameter-growth, a stable stand and to shorten the rotation, this study indicates that a relatively heavy thinning is needed around potential final crop-trees.

Considering that this study is built on data from an R&D project without any other replicates, based on its results and on other studies in the same topic the following thinning strategies could be proposed for sessile oak stands management in Romania:

a. The use of stand density, of maximum 2,000 stems ha^{-1} after the last cleaning-respacing (when mean height is 6-8 cm) and 1,100-1,300 trees ha^{-1} following the application of first thinning (mean height 11-13 m), as also proposed in countries such as France (Jarret, 2004, Sardin, 2008, Sardin and Mothe, 2010).

b. The use of an even level of stocking (basal area) throughout the whole life of the stand, at the level of 14-18 m^2 ha^{-1} after each intervention (Sardin, 2008, Sardin and

Mothe, 2010). The higher level of basal area after intervention (23-25 m^2 ha^{-1} on average), as proposed in the UK (Kerr and Haufe, 2011), seems to be too high for the studied sessile oak stands.

In valuable stands , targeting saw log or veneer log production, the selection and painting of at least “genuine” final crop can be an option.

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