Influence of Initial Density of Oak (*Quercus robur* L.) Plantations on Stem Quality

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Abstract

Studies were carried out in the 46 year-old oak plantations of different initial density (3,570, 7,140, 12,300 ir 20,000 trees ha^{-1}). It was found that the straightness of oak stems at the height of 0.1 – 5.1 m from the ground surface is distinctly dependant on tree diameter. With increasing tree diameter, stem straightness increases as well. The stems of the thinnest trees are by 2 times more crooked (cm m^{-1}), in comparison with the thickest trees. The straightest stems were in plantations of 7,140 trees ha^{-1} initial density. The number of branches and their thickness at 0.1 – 5.1 m height decreases under increasing initial density. Relative distribution of butt logs by quality classes within the range of studied densities is similar, however, with increasing initial density, the number of stems producing butt logs of the highest quality, expressed in percent from the number of planting places, constantly decreases. Second logs, compared with butt logs, most often are of inferior quality and only in exceptional cases the quality is higher. When butt logs are of the highest quality class, only 15% of second logs remain in the same class. Given the growth of plantations and timber quality, the initial density of oak plantations should be between 3,500–7,140 trees ha^{-1}.

Key words: butt log, initial density, pedunculate oak, quality

Introduction

Due to environmental, economic and social significance, pedunculate oak is one of the most important trees in Lithuanian forestry. Despite this, the area of oak stands in 2006 occupied only 40,1 thou. ha or 2% from the total forest area (*Lithuanian Forest Statistics* 2006). Oak stands of high commercial value in the European Union comprise about 5% of the forest area (ONF 1994).

After initiation by M.Lukinas restoration of Lithuanian oak stands in the 1960s and the beginning of the 1970s, when 20 thou. ha of oak plantations were established, annual planting volumes in the subsequent 3 decades comprised only several or several tens of hectares (*Lithuanian Forest Yearbook* 2003). Since 1997, the volumes of oak planting started to increase and at present about 200-300 ha are afforested annually. Due to afforestation program of the former farmland, where oak plantations are established rather often, because oak is a valuable and desired species both from social and environmental point of view, as well as owing to the accepted Regeneration Program of Oak Stands, the area of oak plantations should increase.

There are no works published in Lithuania on the initial density of oak plantations, while those published abroad are scarce as well. In the Nizhnenovgorod region, sown and planted 29-54 year-old plantations of pedunculate oak have been studied. Based on the data of survival and growth, plantations established with the initial density of 8.000-10,000 trees ha^{-1} are recommended (Kuprijanov *et al*. 1991). With increasing initial density of oak plantations, the dimensions and especially mass of oak seedlings significantly decreases. Aiming at stand longevity, it is suggested to establish more sparse plantations (Gorshenin and Gazatulin 1975). In the Voronezh region, the 13-41 year-old oak plantations were studied. The increase in the initial density from 6-14 to 15-21 thou. trees ha^{-1} in the 15-23 year-old plantations reduce by 34.6% mean diameter, while by 16.2% - mean height. Optimal density of 13-15 year-old oak plantations is 7-9, at the age of 17 yr. - 6-7, 21-23 yr. – 3-4 and 39-41 yr. – 1.5-2.0 thou. trees ha^{-1} (Kovaliov 1982). In plantations established in Scotland in 1936, the effect of planting design (from 0.6x0.9 m to 2.30 x 2.0 m) on the growth of pedunculate oak and stem form was studied. Periodically carried out estimations showed better stem form and higher productivity in denser plantations. If the goal is to produce high quality timber, initial density should exceed 2.500 trees ha^{-1} (Riley and Nixon 1993).

Based on the growth data of plantations of different density, A.Lisenkov (1968) suggests to establish oak plantations with 3,1-3,5 thou. trees ha^{-1} at initial density, while A. Savina and M.Zhuravliova

(1978) – 20 thou.trees ha^{-1}. The latter authors admit that in sparse plantations (1.0 x 1.5 m) oak trees are more abundantly damaged by late spring frosts than in dense (0.5 x 0.5 m. or 1.0 x 0.5 m) ones, due to which their survival and growth decrease. The increase in the initial density from 6-14 to 15-21 thou. trees ha^{-1} at the age of 13-17 yr. has increased the survival by almost 1.7 times. The survival of plantations reliably correlates with their initial density (Kovaliov 1982). Polish foresters suggest to mix oak with birch in order to reduce the negative impact of frosts on oak, while M.Lukinas (1967) suggested to establish oak plantations with grey alder.

To produce high quality timber, planting density of oak plantations should be 8,000 trees ha^{-1} or higher (Röhring and Bartsch 1992). Planting design experiments show that seeking to ensure stem straightness, self-cleaning from branches and high timber quality, growing space of oak trees should not reach 1.5 m^2, (Gaul and Stüber 1996, Matic *et al*. 2000). Despite this, to reduce planting costs, planting density in oak plantations is being reduced, *i.e.* distances between and within rows are increased (Rock *et al*. 2004). In Great Britain it is recommended to establish oak plantations, as well as those of other trees, with not lower than 2,500 trees ha^{-1} at initial density (Forestry Commision 1991). The experience of Danish foresters shows that seeking to produce high quality timber, the initial density of oak plantations should be not lower than 4,000 trees ha^{-1}.

The aim of this work is to study the quality of butt logs in oak plantations with different initial density.

Objects and methods

Studies were conducted in the 46 year-old oak plantations of Vaišvydava and Šilėnai forest districts of Dubrava Experimental - Training Forest Enterprise, established with different initial density (3,570, 7,140, 12,300 and 20,000 trees ha^{-1}), without replication. The plantations were established on former farmland, situated along the shores of the artificial lake "Kauno Marios" in southern Lithuania (54^{0}45^1 - 54^{0}53^1 N^1 24^{0}04^1 – 24^{0}09^1 E). The soils on these sites have developed on limnoglacial deposits with soil types intermediate between Eutric Cambisols and Dystric or Eutric Planosoils (ISSS-ISRIC-FAO 1998). At present *Oxalidosa* oak stands are being formed. During cuttings performed 2-3 years ago, trees lagging behind in growth and having poor stem quality were removed, although the prevailing trees in the stand were left untouched. The number of trees remaining after felling was ascertained taking into account the standards of maximally productive oak stand formation (Kairiūkštis *et al.* 1980).

During the studies, the diameters of all trees were measured, as well as the heights of 1-4 trees within each thickness group. Stem crookedness was measured at the height of 0.1-5.1 m from the ground surface. Determining stem crookedness, the ends of a stem segment were connected with a straight line and the distance between the line and the stem was measured. The diameters of the thickest branches were measured in the segment of indicated length.

The diameters were measured perpendicularly to the axis line of branches at 3 cm distance from the stem. Based on the requirements of the LST EN 1316-1 standard, estimation of stem segments at the height of 0.1-5.1 m was done, forecasting their correspondence to the quality classes of sawn logs at the age of maturity. During the estimation, crookedness, branchiness and diameter were taken into consideration.

To ascertain the number and volume of trees harvested during thinnings, the diameter of stems was measured. Based on stem diameter at stump level and correlation at the height of 1.3 m, the diameter of harvested trees at the height of 1.3 m was calculated (Butėnas *et al.* 1983).

The belonging of secondary oak logs (at 5.1-10.1 m height from the ground surface) to sawn logs quality classes was determined visible, taking into consideration the same indices as for butt logs (sweep, thickness of branches, stem diameter, bifurcation or multiple tops).

Results

Dendrometric characteristics of oak plantations reflects the influence of the initial density and thinning (Tables 1 and 2). The highest mean diameter, height and stem volume are found in plantations of

Table 1. Dendrometric characteristics of oak plantations

Initial density, trees ha^{-1}	Planting design, m	Number of trees, trees ha^{-1}	D B H,cm	Mean height, m	Volume, m^{3}ha^{-1}
3,570	4.0 x 0.7	560	25.5	24.0	326
7,140	2.0 x 0.7	953	16.9	19.3	222
12,300	1.16 x 0.7	954	18.2	20.2	262
20,000	1.0 x 0.5	682	19.5	20.6	216

Table 2. Dendrometric characteristic of harvested part of the stand

Initial density, trees ha^{-1}	Number of harvested trees, trees. ha^{-1}	Mean diameter of the harvested trees, cm	Volume of the harvested trees, m^{3}ha^{-1}
3,570	172	13.4	23
7,140	713	10.9	81
12,300	467	9.0	25
20,000	452	8.6	24

the least initial density, the lowest growing stock volume - in plantations of the highest initial density.

Prior to thinning, with increasing initial density, the growing stock volume gradually decreases. Before thinning, the highest mean stem diameter was found in plantation with the lowest initial density, the lowest - in plantations with 7,140 trees ha^{-1} initial density, where the number of trees was the largest (1,666 trees ha^{-1}). The least diameter in these plantations remained after cuttings as well.

At the level of but logs (at 0.1 – 5.1 m height), the straightest stems were in plantations with 7,140 trees ha^{-1} at initial density (1.48 cm m^{-1}), the most crooked – 12,300 trees ha^{-1} (1.82 cm m^{-1} , Table 3). Stem crookedness depends on the relative tree diameter. With increasing relative tree diameter (*i.e.* relative diameter – distributions of trees under diameter, expressed in parts from the mean stand diameter), stem crookedness decreases (Figure 1). This dependance is distinct and manifested itself in plantations of all densities. Determination coefficients of the equations 0.42 – 0.61. The difference of stem crookedness between the thickest and the thinnest trees comprises about 2 times.

Table 3. Crookedness of the stem at the height 0.1 – 5.1 m, mean diameter of the thickest branches and number of trees with branches in oak plantations of various initial density

Initial density, trees ha^{-1}	Crookedness of the stem cm m^{-1}	Mean diameter of the thickest branches, cm	Number of trees with branches at the stem height 0.1 – 5.1 m, %
3,570	1.76 ± 0.13	3.6	40
7,140	1.48 ± 0.10	3.4	10
12,300	1.82 ± 0.14	3.0	22
20,000	1.67 ± 0.12	-	0

The mean diameter of the thickest branches decreases with increasing initial density of plantations. The number of trees with branches decreases as well with increasing initial density, while in plantations of 20 thou. trees ha^{-1} at initial density trees with branches at the height of 0.1 – 5.1 m were absent.

Forecast of the distribution of oak stem segments at the height of 0.1-5.1 m by quality classes according to their correspondence to sawn logs when stands approach maturity has shown that with increasing initial density, the number of potential stems of the highest quality class initially increases, while later it decreases (Table 4). Relative distribution of oak butt logs by quality classes is similar in the plantations of all initial densities and on an average class A trees comprise about 29%, class B - 41%, C - 27% and D - 3% (Figure 2). With increasing initial density, the number of potentially best quality logs, expressed in percent from the number of planting places, constantly decreases. In plantations with 3,570 trees ha^{-1} at ini-

Table 4. Forecast of oak stems distribution at the height of 0.1-5.1 m by quality classes according to their correspondence to sawn logs at the age of stand maturity (trees ha^{-1})

Initial density, trees ha^{-1}	Quality classes			
	A	B	C	D
3,570	168	241	140	11
7,140	215	389	309	40
12,300	298	343	253	60
20,000	214	292	166	10

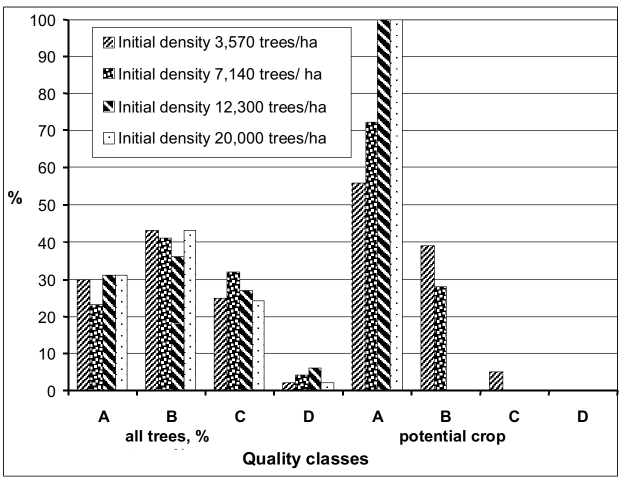

Figure. 1. Dependance of stem crookedness on the relative tree diameter

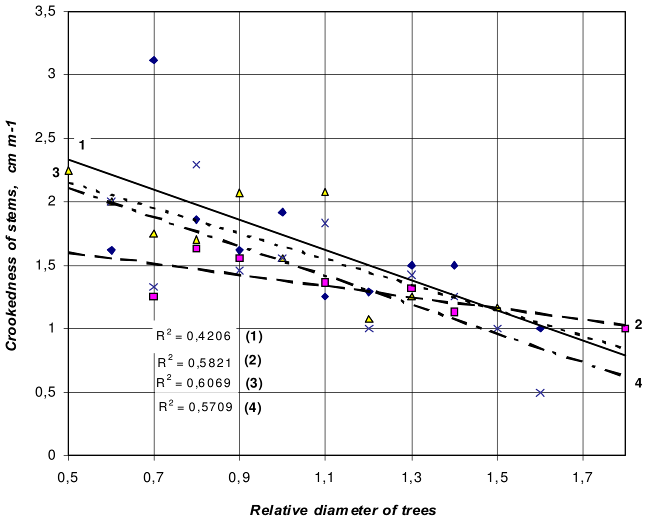

Figure 2. Distribution of butt logs by quality classes

tial density the number of such stems comprises 4.7%, with 7,140 trees ha^{-1} – 3.0%, 12,300 trees ha^{-1} – 2.4%, while with 20,000 trees ha^{-1} – only 1.1%.

Quality class of the second logs, in comparison with butt logs, most often changes in the direction of worsening (Table 5). Secondary logs, when but logs are of class A, remain of the same class in 16% of trees, when butt logs are of classes B and C – 25%. Quality class most often changes over 1 class. Changes over 2 or 3 classes on average comprise only about 14%. Quality class changes in the direction of improvement are very rare and make up only about 1%.

Table 5. Forecast of the survival of secondary logs in the same quality class, compared with butt logs

Initial density, trees ha^{-1}	Survival in the same quality class, %		
	A	B	C
3,570	21	9	25
7,140	10	35	40
12,300	10	17	24
20,000	23	40	12

Discussion

The highest mean diameter of plantations was found in the plantations with less initial density. The same dependance was ascertained by S. Hannelius (1978), J.Adegbeihn (1982), T.Classon (1994). The highest mean height and growing stock volume were found in plantations of the lowest initial density as well. The mean height and growing stock volume of plantations is the function of the initial density and age. At the juvenile stage higher and more productive are dense plantations, later gradually the superiority of less density stands is revealed (Merzlenko 1981; Kairiūkštis and Juodvalkis 1985; Orlič Steno 1987; Juodvalkis and Jonikas 1988; Kenk 1988; Classon 1994).

The thickness of branches, especially for broadleaved hardwoods, is one of the main indices of wood value (Röhring and Gussone 1990, Nutto 1999). In plantations with 20 thou. trees ha^{-1} planting density, branches at the height of 0.1-5.1 m were absent. With decreasing initial density, the number of branches and their thickness were increasing, which completely corresponds to the regularities ascertained in most other works. Another important factor of logs quality is stem form. The most desirable stems are straight and vertical ones (Rock *et al.* 2004). Deviations from this form affect stem straightness and are determined by genetic factors (crown type, Gockel 1994), damages of apical shoot (Leder 1992), or stem sweep. The straightest stems at the height of 0.1-5.1 m from the ground were found in plantations with 7,140 trees ha^{-1} at initial density. Studies of pine and spruce plantations by O. Huuri E. Lahde (1985), F. Prescher and E. Stähl (1986) and E. Agestam *et al*. (1998) have shown that with increasing initial density, stem straightness increases. With increasing initial density of spruce plantations up to 12,500 trees ha^{-1}, stem straightness increased, while later, with increasing initial density, it started to decrease (Kairiūkštis and Malinauskas 2001). In hybrid aspen (*Populus tremula* x *Populus tremuloides*) plantations the straightest stems were in plantations of the lowest (500 trees ha^{-1}) initial density (Malinauskas and Urbaitis 2006). Stem crookedness of trees in the plantations of average and high initial density was increased by their bending in the direction of better light conditions.

The straightest stems in coniferous plantations are those of average and close to their dimensions trees (Kairiūkštis and Malinauskas 2001, Malinauskas 1999, 2003). With increasing diameter of trees, the crookedness of oak stems decreases. If competing with an individual oak trees surround it, while competition is similar in all directions, then the tree has no other choice how to grow in height, however, if the competitors are only on one side, the oak reacts to this by retreating the stem and crown, due to what changes its stem form, and it greatly affects the quality of wood (Rock *et al*. 2004). In the plantations of hybrid aspen, the straightest were the thickest trees (Malinauskas and Urbaitis 2006). Thus, the stems of oaks as well as those of hybrid aspens are considerably affected by light conditions. While growing, they bend in the direction of better light conditions.

Relative distribution of butt logs by quality classes in the plantations of different densities is similar. This might have been determined by a low diversity of the initial density of the studied plantations and genetic properties of oak. With increasing initial density up to 12,300 trees ha^{-1}, the number of trees with potential butt logs of the highest quality was increasing per area unit, while in plantations with 20,000 trees ha^{-1} at initial density it again became lower. On the other hand, with increasing initial density, the number of stems with potentially best quality butt logs, expressed in percent from planting places, was gradually decreasing. This distribution of butt logs by quality classes was determined by the genetic properties of oak and the absence of thinning (too late thinning).

Taking into account the growth of plantations and the quality of timber, minimal initial density of oak plantations should be not less than 3,500 trees ha^{-1}. Seeking to produce higher amount of the highest quality timber, the initial density of plantations should be increased up to 8,000 thous. trees ha^{-1}, however, such an increase in the initial density would significantly increase the costs of plantation establishment. To reduce the costs, it is suggested to establish plantations in clusters (Gockel 1994). The first oak plantations in clusters were established in Lithuania in the sixth decade of the XX century. The density of oaks in the clusters should be rather high (tree nutrition area is about 1 m^2) to ensure strong intraspecific competition in young stands. Each cluster should contain one vigorous oak tree of high wood quality. Thus, the size of cluster would depend on the genetic quality of seedlings. Study results show that in each cluster should be planted about 20-40 oak trees. Improving the genetic quality of seedlings, this number could decrease. The number of clusters per area unit depends on the final crop trees density. Aftercare of plantations would be carried out only in the clusters, which would reduce stand establishment costs (Gockel *et al.* 2001). Establishment of oak plantations in clusters would also increase biodiversity, in comparison to forest establishment on the whole area, because the area between clusters would be left for natural regeneration (Rock *et al*. 2003). Fast growing softwood broadleaves could reduce the danger of damages of late frosts on oak plantations.

Conclusions

1. The growth of oak plantations (the mean diameter and height as well as growing stock volume), depending on the initial density, conform to the same regularities, determined studying other tree species.

2. The straightness of oak stems obviously depends on tree diameter. With increasing tree diameter, the straightness of oak stems increases as well. The straightest stems are in plantations with 7,140 trees ha^{-1} at initial density.

3. Relative distribution of butt logs by quality classes within the range of studied densities (3,570-20,000 trees ha^{-1}) is similar, however, with increasing initial density, the number of potential crop trees, expressed in percent from planting places, gradually decreases. Second logs, in comparison with butt logs, most often are of worse quality. When butt logs are of the highest quality, only 15% of second logs remain of the same class. Taking into account the growth of plantations and the quality of timber, the initial density of oak plantations should be between 3,500 – 7,140 trees ha^{-1}.

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ВЛИЯНИЕ НАЧАЛЬНОЙ ГУСТОТЫ КУЛЬТУР ДУБА (*QUERCUS ROBUR* L.) НА КАЧЕСТВО СТВОЛОВОЙ ДРЕВЕСИНЫ

А. Малинаускас

Резюме

Проведены исследования насаждений дуба обыкновенного различной начальной густоты (3,570, 7,140, 12,300, 20,000 шт. га $^{-1}$) 46–летнего возраста. Установлено, что кривизна стволов дуба на высоте 0.1-5.1 м от поверхности почвы значительно зависит от диаметра деревьев. При увеличении диаметра деревьев кривизна стволов уменьшается. Кривизна стволов самых тонких деревьев почти в 2 раза больше (см м^{1}), по сравнению с наиболее толстыми деревьями. Наибольше прямолинейных стволов установлено при начальной густоте 7,140 шт. га$^{-1}$. При увеличении начальной густоты количество и диаметер сучьев на высоте стволов 0.1-5.1 м уменьшается. В пределах изучаемых густот относительное распределение первичных бревен по классам качества является близким, но при увеличении начальной густоты процент количества первичных бревен наивысшего класса качества, выраженный от числа посадочных мест, постоянно уменьшается. Вторичные бревна, по сравнению с первичными, в большинстве случаев бывают худшего качества и только в исключительных случаях – лучшего. Только 15% вторичных бревен остаются в той же самой классе качества, если первичные бревна - наивысшего класса качества. При учете роста культур и качества выращиваемой древесины густота посадки дуба должна быть не меньше чем 3,500 шт. га$^{-1}$.

Ключевые слова: дуб обыкновенный, качество, начальная густота, первичные бревна