The Influence of the Initial Density on Spruce (*Picea Abies* Karsten.) Wood Quality

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The investigation has been conducted on different initial density (820; 1,970; 3,010; 6,500; 12,500; 25,000; 50,000 and 100,000 seedlings ha^{-1}) of 39-year-old spruce plantations of square distribution. They have been established in the Dubrava experimental-training forest district on completely prepared soil by planting two-year-old seedlings of local origin. Tending fellings have not been carried out.

It has been determined that the initial density of plantations influences the extent of stem thinning towards the top, stem straightness, the number of branches in a whorl and in the part of the stem, which is between the height of 1 and 2 m, the ratio of ring width of early wood to that of late wood as well as wood basic density. By increasing the initial density from 820 to 12,500 plantings ha^{-1} stem straightness augments whilst due to a further increase in the initial density it starts diminishing. With increasing initial density the mean diameters of all branches and the thickest ones decreases. In case the initial density is augmented up to 3,010 plantings ha^{-1} its influence on the thickness of branches is most significant. An increase in the initial density up to 1,970 seedlings ha^{-1} exerts no influence on the number of branches in a whorl nor on that in the part of the stem between the height of 1 and 2 m. Due to an increase in the initial density from 1,970 to 12,500 ha^{-1} seedlings the number of branches in a whorl diminishes from 28 to 33%. With increasing height of a whorl from 1.5 to 5.5 m from the soil surface the number of branches in a whorl decreases whilst the thickness enlarges.

The initial density has a great influence on the width of tree rings, statistically reliable influence on the ratio of early wood to late wood and slight although statistically reliable but practically insignificant influence on wood basic density.

Key words: Norway spruce, initial density of plantations, the number of branches, stem straightness, wood basic density.

Introduction

The experience gained in forestry science and practice over the last 50 years shows that the initial density of spruce plantations in the forests of Lithuania has noticeably decreased.

In early post-war years, when spruce no longer was sown in squares, from 10 to 25 thousand seedlings ha^{-1} were still planted in the soil prepared in different ways. Later the initial density of spruce plantations stepwise lessened up to 2.5-4.0 thousand plantings ha^{-1}. Due to poor survival of plantings during the first years of the growth actual density of plantations was even less and sometimes attained only 1.5-2 thousand plantings ha^{-1}.

As we know, plantation density to a large extent conditions not only stand growth, sustainability but also the quality of the grown production. The major indexes of the quality of round wood are straightness, the number of branches, the width of tree rings, which to a certain extent reflects physical-technical properties of wood.

The results of the investigations carried out in different countries have indicated that the initial density and the quality of spruce wood are closely connected (Klem 1952; Ericson 1966; Persson 1975; Vyskot 1978; Brazier, Mobs 1993; Johansson, Petersson 1997; Sjölte-Jorgensen 1967; Lindstrom 1996). The data obtained by the above authors imply the feasibility to improve the quality of wood through an increase in the initial density of plantations. Hitherto, in Lithuania the effect of the initial density on the quality of spruce wood has not been investigated. Studies have been conducted only on the number of branches of Norway spruce in stands of natural regeneration, depending upon nutrition area of a tree, soil fertility and moisture (Arlauskas 1979). The choosing of the initial density, of course, is conditioned by a number of ecological, economic, technical factors as well as by the price of plantings and labour consumption for planting. The aim of our investigations was to determine the influence of the initial density on stem straightness of Norway spruce, the number of branches, the width of annual tree rings and on wood basic density.

Data and methods

In order to resolve the issues above and investigate the growth regularities of trees entering coenosis and subsequent formation of stem quality we established special spruce plantations of different density in the Dubrava experimental training forest district (Kairiūkštis, 1995). Two-year-old uniform seedlings were planted in 1958 at regular spacing with the density of 100,000; 50,000; 25,000; 12,500; 6,500; 3,010; 1,970; 820 seedlings ha^{-1}. The plantations were raised in completely prepared soil by using plantings of local origin. Currently, it is 45-year-old spruce stand of Oxalis forest type. The plantations were established without repetition. Tending fellings were not carried out. The area of a density variant was 0.05 hectare.

The measurements of tree growth and branch forming were made annually in 1963-1974. Later they were repeated at plantation age 39 years. The diameter of all trees was measured at breast height. After that in a systematic-random way (according to the diameters of trees) 50 trees were selected in every density variant. Their height was measured up to the first live branch and their diameter at 5.5 m height. The number of stem bendings was determined and stem straightness assessed. The thickness of branches was measured in the part of the stem from 1 to 2 m high as well as that of branches in a whorl at the height of 3.5 and 5.5 m. Measurements of the diameter of branches were made at the distance of 3 cm from the stem perpendicularly to branch axis at the accuracy of 1 mm. Stem straightness was scored from 1 to 5 with the straight stems assigning a score of 1 and with crooked stems inappropriate to sawn timber assigning a score of 5. In density variants 820; 1,970; 3,010; 6,500 and 12,500 seedlings ha^{-1} from 20 trees selected in a systematic-random way in each variant 2 samples were taken by Presler's borer at 1.3 m height. The width of rings was measured and wood basic density determined. The boring was oriented towards south east and south west. Wood volume was ascertained measuring the length (at the accuracy of 1.0 mm) and thickness (at the accuracy of 0.001 mm) of the sample soaked in ethyl alcohol. Thus, maximal error of determination of sample volume should not exceed 4%. Wood mass was determined measuring the samples dried at 105°C. The accuracy of measurement was 0.0001 g. Wood basic density was ascertained dividing absolutely dry wood mass by the volume of raw wood.

Results

The initial density of plantations crucially affects not only the average stem volume, stand diameter and height but also the height up to the first live branch and crown length (Table 1).

Table 1. Dendrometric characteristic of 39-year-old spruce plantations of different density

The initial density of plantations, seedlings ha^{-1}	Survival, %	The number of trees at age 39 years, trees ha^{-1}	The mean diameter, cm	The mean height, m	Basal area, m^2 ha^{-1}	The current increment, m^3 ha^{-1}	Stem volume, m^3 ha^{-1}
820	90	741	24.0	18.2	33.6	16.5	290
1970	79	1498	18.7	19.1	41.2	18.5	404
3010	67	2161	16.3	18.1	44.9	15.8	419
6500	48	2974	14.3	17.2	47.9	18.2	430
12500	33	4076	10.9	14.6	38.3	12.9	277
25000	20	5108	10.0	13.8	40.6	14.6	273
50000	12	6127	9.7	12.8	45.2	15.8	278
100000	8	8271	8.0	11.0	41.3	12.6	212

The presented data correspond to the regularities of the growth and development of plantations of different density, which have been studied by a number of authors.

The height up to the first live branch in closed plantations is closely connected with the height of trees. The most significant mean height (19.1 m) is in the plantations where the initial density was 1,970 seedlings ha^{-1}. Also in the same plantations (Fig. 1) the height up to the first live branch (12.6 m) is characterized as most significant. With increasing density of plantations and with decreasing mean height of a tree the height up to the first live branch diminishes. It diminishes less than the mean height of trees. Such a change in the height of a tree and in that up to the first live branch conditions crown length. The longest (9.1 m) crowns are in the plantations of the lowest (820 seedlings ha^{-1}) density. By increasing the initial density up to 50,000 plantings ha^{-1} crown length gradually diminishes. It is identic (3.6 m) in the plantations where the initial density was 50,000 and 100,000 seedlings ha^{-1}. In older spruce plantations crown length is considerably affected by snow break, icing and other natural factors as well as by sudden crown differentiation injuring stand structure and, consequently, distorting regular formation of crown length.

Stem straightness depends upon the number and extent of bendings. The number of stem bendings in the plantations where the initial density was from 820 to 25,000 seedlings ha^{-1} ranges from 0.6 to 0.9 (Table 2). The differences between density variants are not statistically reliable even in case $P<0.05$. The number of stem bendings in the plantations with very high initial density (50,000 and 100,000 seedlings ha^{-1}) is

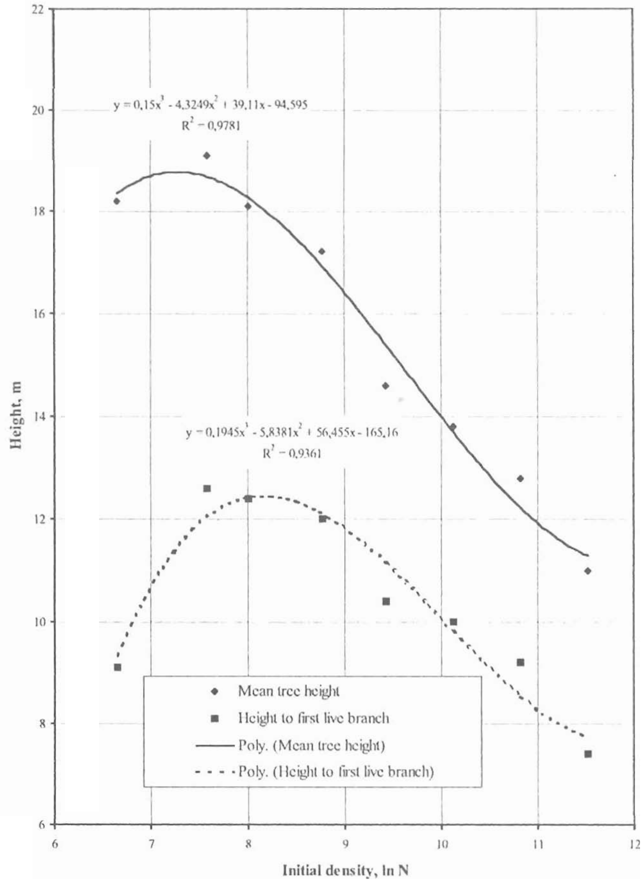

Figure 1. Mean tree height and height to first live branch in the 39-year-old plantations of various initial density

Table 2. The diameter of branches at the height of stem from 1 to 2 m and stem straightness in plantations of different initial density

The initial density of plantations, seedlings ha⁻¹	Relative diameter of branches	The mean diameter of branches	The mean diameter of the thickest branches, mm	The number of stem bendings	Stem straightness
820	0.106	10.1±0.4	25.4±0.6	0.8±0.1	2.1±0.2
1970	0.088	8.5±0.3	16.5±0.5	0.9±0.1	1.8±0.1
3010	0.080	7.2±0.2	13.1±0.5	0.8±0.1	1.6±0.1
6500	0.080	6.1±0.2	11.5±0.4	0.9±0.2	1.6±0.1
12500	0.087	5.8±0.2	9.5±0.4	0.6±0.1	1.5±0.1
25000	0.082	5.2±0.1	8.2±0.4	0.8±0.1	1.6±0.1
50000	0.108	4.6±0.1	7.8±0.3	1.3±0.2	2.0±0.1
100000	0.085	4.2±0.1	6.8±0.3	1.6±0.2	2.4±0.2

by far larger and attains 1.3 and 1.6, respectively. Here the differences are statistically reliable in case $P<0.01$. By increasing the initial density up to 12,500 ha⁻¹ seedlings stem straightness augments. Further increase in the initial density results in a decrease in stem straightness. The differences are statistically reliable ($P<0.05$) between the plantations with 12.5 and 0.82 as well as with 50 and 100 thousand seedlings ha⁻¹.

The extent of stem taper within the butt log at 1.3-5.5 m height depends both upon the initial density (Fig. 2) and the diameter of a tree (Fig. 3). Due to an increase in the initial density of plantations the extent of stem taper towards the crown diminishes and due to enlargement of the diameter of a tree augments.

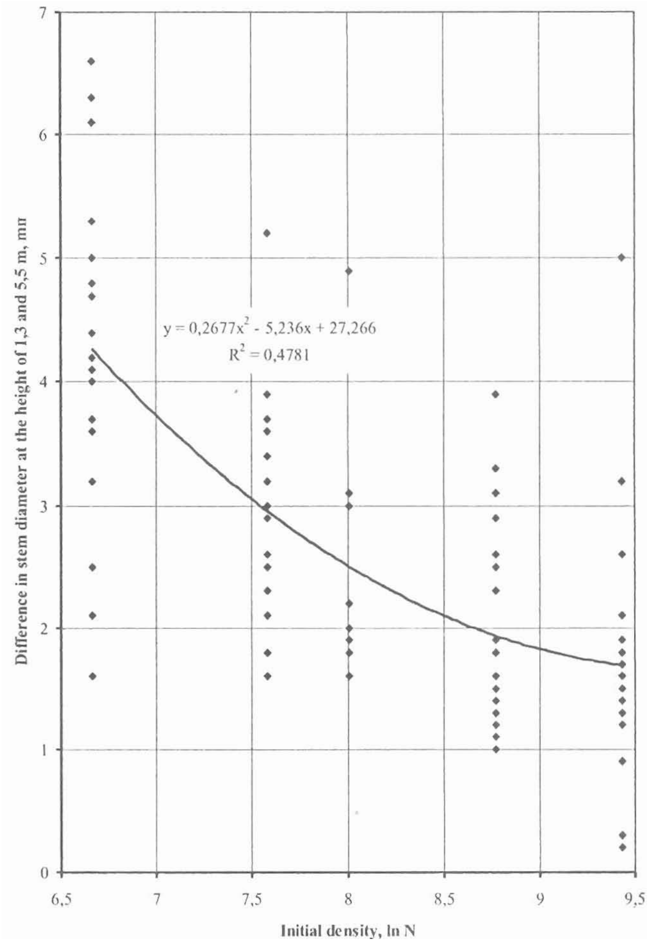

**Figure [illegible]fference in stem diameter at the height of 1,3 and 5,5 m in relation with the initial plantation density

The quality of wood largely depends upon the number of branches and their thickness. The largest number of branches is found in the plantations where the initial density was 820 and 1,970 seedlings ha⁻¹. In these density variants there are 57 branches (Fig. 4) per 1 m of stem. With increasing density of planting the number of branches starts diminishing. In the plantations where the initial density was 100 thousand seedlings ha⁻¹ there are only 30 branches per 1 m of stem. The largest number of branches of 20 mm and thicker ones attains 5.5 in the plantations where the initial density was 820 seedlings ha⁻¹. With increasing density the number of such branches diminishes. In the plantations where the initial density was 3,010 seedlings ha⁻¹ it comprises only 0.1 branch per 1 m of

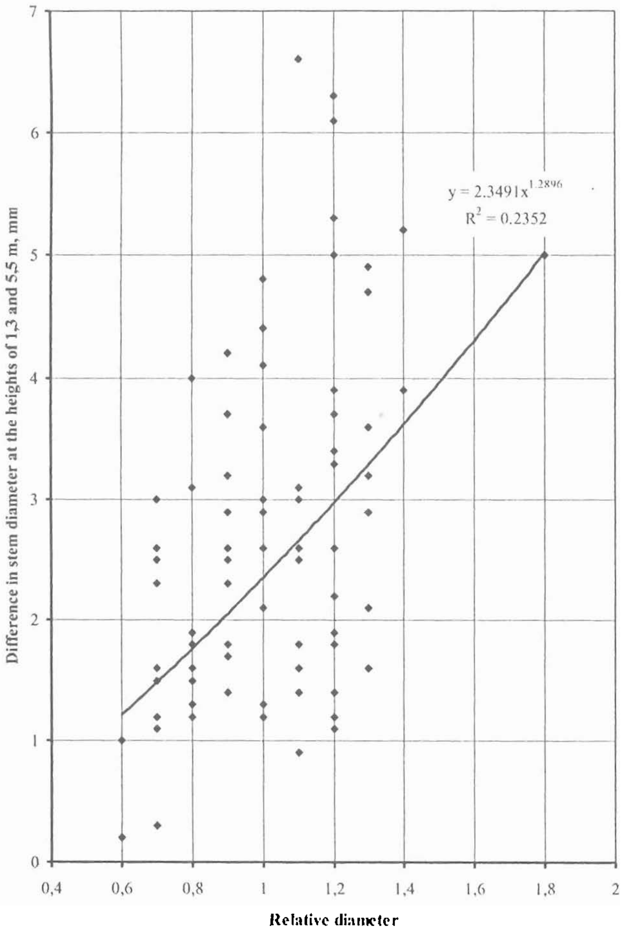

Figure 3. Difference in stem diameter at the heights of 1,3 and 5,5 m in relation with the relative diameter

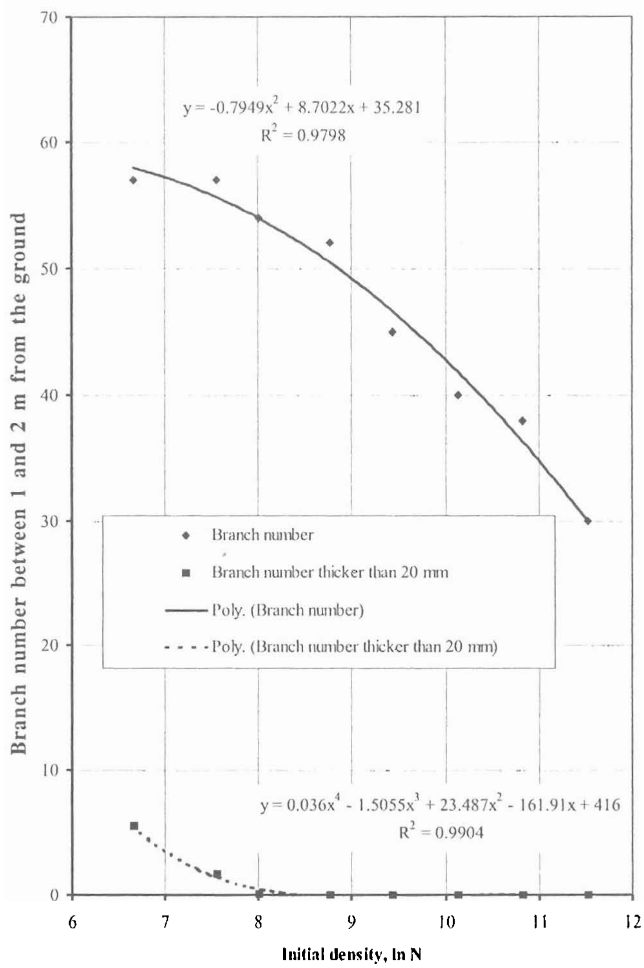

Figure 4. Branch number in the first log between 1 and 2 m of height in relation with the initial density of plantations

stem. At larger initial density branches of 20 mm and thicker ones occur only occasionally when near the growing tree one or several trees die and free space appears.

Trees in the plantations of the lowest density are typical of the largest number of branches and largest (10.1 mm) mean diameter (Fig. 5). With increasing density in plantations the mean diameter of branches step by step decreases. When the initial density attains 100,000 seedlings ha^{-1} it is 4.2 mm, i.e. nearly 2.5 times less. The differences between the mean diameter of branches in plantations with different density variants are statistically reliable ($P<0.01$) excluding the plantations where the initial density was 6,500 and 12,500 seedlings ha^{-1}.

Relative diameter of branches expressed as a ratio of the diameter of the thickest branches to that of trees at breast height appears to be least in the plantations (Table 2) where the initial density was 3,010 and 6,500 seedlings ha^{-1}. The differences between density variants are insignificant.

In the plantations where the initial density was 820 plantings ha^{-1} the mean diameter of the thickest branches is 25 mm. By increasing the initial density it rapidly lessens and at initial density 100,000 seedlings ha^{-1} attains only 6.8 mm. The differences between the mean diameter of the thickest branches in density variants from the thinnest plantations up to 12.5 thousand plantings ha^{-1} are statistically reliable ($P<0.01$). At more significant initial density the differences between density variants become statistically unreliable.

In comparison to the height of 1.5 m, at more significant height of the stem from the ground surface (3.5, 5.5 m) the number of branches in a whorl diminishes whereas the mean diameter and the diameter of the thickest branches enlarge (Fig. 5 and 6). The differences between the number and thickness of branches in the whorls at the height from 1.5 to 3.5 m are greater than between these at the height from 3.5 to 5.5 m.

It has been found that wood basic density largely depends upon the initial density (Table 3) of plan-

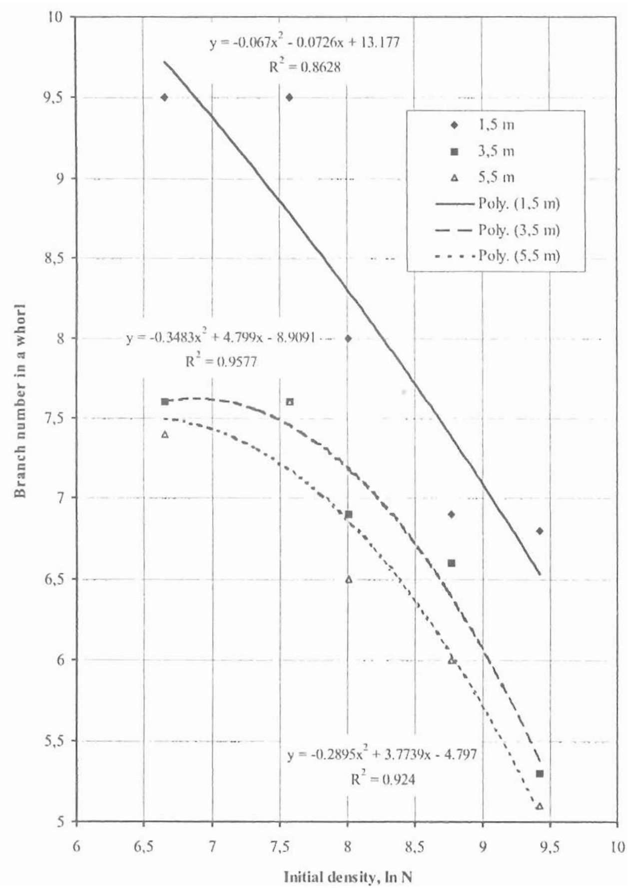

Figure 5. Branch number in a whorl at the heights of 1.5, 3.5 and 5.5 m

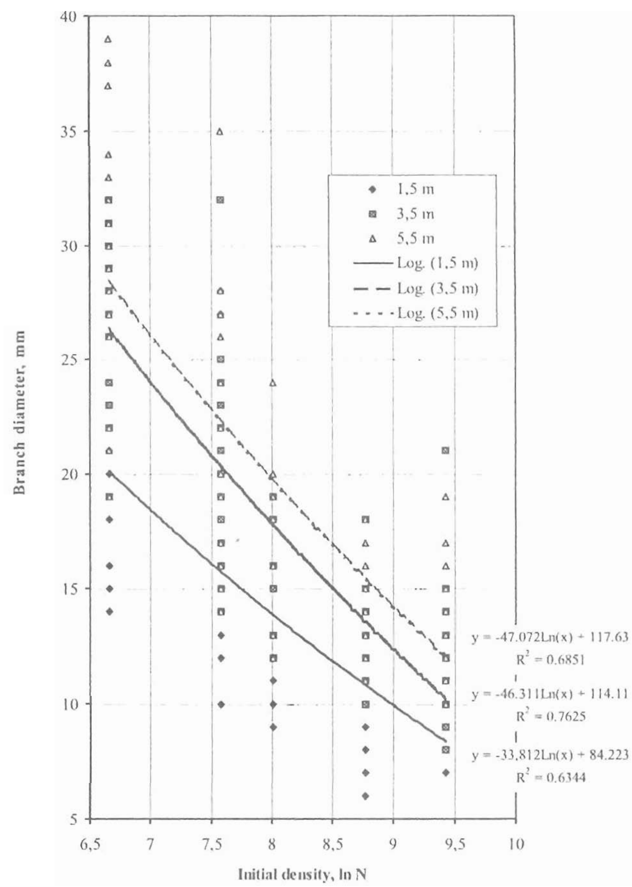

Figure 6. Mean diameter of the thickest branches in a whorl at the heights of 1.5, 3.5 and 5.5 m.

tations. The most significant basic density of spruce wood is in the plantations of average initial density (1,970; 3,010 seedlings ha^{-1}). The least wood basic density is near the core. With increasing age wood density augments too.

Wood basic density also depends upon the position of a tree in the stand (Fig. 7). Less basic wood density is typical of slowly and vigorously growing trees. Wood basic density of average and slightly larger ones, i.e. with relative diameter 1.0-1.2 (class B and A), is found to be highest. However, high wood basic density occurs among slowly growing trees and among the thickest ones. Significant variability (variation coefficient ranges from 10.5 to 12.9%) of wood density is typical of different trees. The ratio of late wood to early wood depends upon the initial density and position of a tree in the stand and varies like wood basic density (Table 4).

Table 3. Wood basic density

The initial density of plantations, seedlings ha^{-1}	Wood basic density at 1.3 m height according to the groups of tree rings from the core up to the bark, kg m^{-3}			
	1-10	11-20	20<	1<
820	369±8.7	392±12.2	433±8.7	398±6.8
1970	372±7.0	399±7.7	455±7.7	409±6.3
3010	371±5.5	394±5.5	449±8.6	403±5.5
6500	371±6.4	396±8.3	442±6.7	400±6.0
12500	373±4.6	388±6.0	437±7.5	397±5.4

The coefficients of the correlation, which indicate the relationship between the quality indexes of different stems and initial density are presented in Table 5. High and distinct (P<0.001-0.001) correlation has been established between the diameter of a tree, height from the ground surface up to the first live branch, the number of branches on the stem at the height from 1 to 2 m, the diameter of the thickest branch and initial density. Also high and distinct correlation is between the height from the ground surface up to the first live branch, the number of branches on the stem at the height from 1 to 2 m, the diameter of the thickest

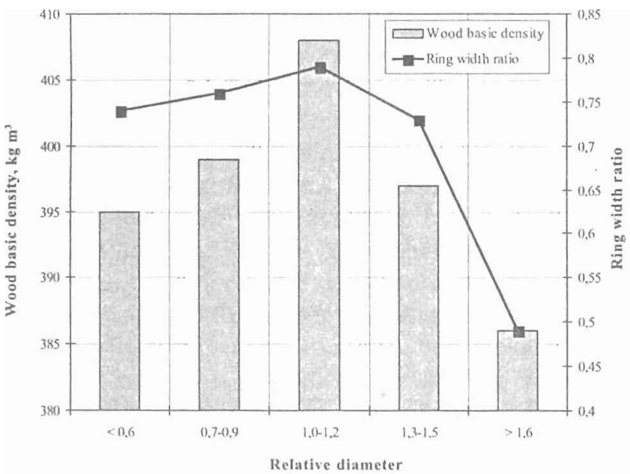

Figure 7. Wood basic density and late / early wood ratio in relation with tree relative diameter

Table 4. The mean width of tree rings and the ratio of ring width of late wood to that of early wood

The initial density of plantations, plantings ha⁻¹	Tree ring width, mm			The ratio of tree ring width of late wood to that of early wood		
	Tree ring age from the core towards the bark at 1.3 m height					
	1-20	≥21	>1	1-20	≥21	>1
820	4.10±0.12	2.05±0.06	3.19±0.10	0.57	0.84	0.69
1970	3.49±0.10	1.08±0.03	2.46±0.09	0.71	0.91	0.80
3010	2.97±0.09	1.06±0.03	2.12±0.06	0.80	0.87	0.83
6500	2.51±0.08	0.98±0.03	1.85±0.05	0.74	0.83	0.78
12500	1.76±0.06	0.90±0.03	1.38±0.04	0.73	0.75	0.74

Table 5. The coefficients of the correlation between the initial plantation density and quality indexes of stems

	The diameter at 1.3 m height	The height from the soil surface up to the first live branch	The number of branches on the stem at the height from 1 to 2 m	The mean diameter of the thickest branch	Relative diameter of a branch	Wood basic density
The height from the ground surface up to the first live branch	-0.782ˣˣ					
The number of branches on the stem at the height from 1 to 2 m	-0.910ˣˣ	0.744ˣˣ				
The mean diameter of the thickest branch	-0.608ˣˣ	0.203	0.798ˣˣ			
Relative diameter of a branch	0.-0.065	-0.448ˣˣ	0.004	0.391ˣ		
Wood basic density	-0.659ˣˣ	0.384ˣ	0.737ˣˣ	0.410ˣˣ	0.178	
The initial density of plantations	-0.703ˣˣ	0.388ˣ	0.893ˣˣ	0.578ˣˣ	0.277	0.224

ˣ the differences are statistically reliable in case P<0.01, ˣˣ in case P<0.001

branch, wood basic density and the diameter (P<0.001) of a tree. The correlation between the relative diameter of a branch and diameter of a tree is insignificant. Also weak correlation is between the relative diameter of a branch, wood basic density and initial density of plantations.

Discussion

The effect of the initial density of plantations on stand parameters, i.e. the diameter, height, stand basal area *etc*, and a variation in them during stand growth is obvious. It is rather thoroughly described in the special literature of forestry. In our investigations the obtained results correspond to already known regularities since the diapason of the initial density was very wide. As seen from the mean stand basal area, height and volume, already at initial density 1,970 seedlings ha^{-1} stand productivity (404 m^3 ha^{-1}), which is close to maximal, and particularly large (18.5 m^3 ha^{-1}) current increment are ensured. Also maximal stand productivity (430 m^3 ha^{-1}) at age 39 years is in the plantations with initial density 6,500 seedlings ha^{-1}. Johansson, Petersson (1997) investigated 43-year-old spruce plantations of different density (1.5×1.5, 1.8×1.8, 2.1×2.1, 2.5×2.5 m). They have also determined that the most dense plantations (1.5×1.5 m) are maximally productive.

The initial density significantly conditions the height from the soil surface up to the first live branch. The dependence of the height up to the first live branch on the initial density was investigated by Braastad (1970, 1979), Haveraaen (1981), Handler and Jakobsen (1986), Johansson (1992). In density diapason 1×1 - 3×3 m investigated by these authors it has been found that with increasing initial density the height up to the first live branch at the beginning increases and later starts diminishing, i.e. changes like the average height of plantations. In our investigations within a wide diapason of the initial density it has been determined that the height up to the first live branch increases more (up to 1,970 seedlings ha^{-1}) and later decreases less as compared to the average height of plantations. Such a change in the height of a tree and in that up to the first live branch, which is caused by the initial density, crucially affects crown length. With increasing density crown length decreases from 9.1 (820 seedlings ha^{-1}) to 3.6 m (100,000 seedlings ha^{-1}). In the stem young wood is more intensively produced in the part of a crown and under it (Elliott 1970) and crown length depends upon the initial density. Consequently, it can affect the characteristic of wood fibre.

By increasing the initial density up to 12,500 seedlings ha^{-1} stem straightness augments and later starts diminishing. The initial density did not influence the number of bendings of stem nor the bending near the stump.

By increasing the initial density from 820 to 3,010 seedlings ha^{-1} the mean diameter of the thickest branch diminishes 12.3 mm and by increasing it from 820 to 100,000 seedlings ha^{-1} 18.6 mm. The influence of the initial density on the thickness of branches has been assessed by Braastad (1970; 1979), Haveraaen (1981), Moltesen et al. (1985), Handler and Jakobsen (1986), Johansson (1992) and Vestal, Colin, Loubere (1999). In all these investigations due to an increase in the initial density the thickness of branches diminishes. Difficulties arise in comparing our data with these obtained by other authors because branches were measured at other height by applying different methods. The mean diameter of the thickest branch in our plantations at initial density 3,010 seedlings ha^{-1} has been compared with that determined by Johansson (1992) in the plantations at initial density 3,086 seedlings ha^{-1}. It has been found that the diameter ascertained by us is 1.9 mm less.

The diameter of branches more closely correlates with the diameter of a tree than with the initial density. The correlation between the diameter of branches and that of a tree is high and distinct. Nylinder (1959), Moltesen et al. (1985) and Johansson (1992) have also determined high correlation between the diameter of branches and that of a tree. The dependence of the diameter of branches on the initial density is less than on the diameter of a tree. It is corroborated by weak relationship between the initial density and relative diameter of branches.

By increasing the initial density from 1,970 to 100,000 seedlings ha^{-1} the number of branches per 1 m of stem decreases 27, i.e. nearly twice, and by increasing it from 1,970 to 12,500 seedlings ha^{-1} the number of branches in a whorl diminishes 2.7. After Moltesen et al. (1985), Handler and Jakobsen (1986) and Nylinder (1959) density slightly influences or does not influence the number of branches in a whorl. Nylinder (1959) considers that the number of branches in a whorl depends upon genetic factors while environmental effect is intangible. For Norway spruce Johansson (1992) has determined a decrease in the number of branches in a whorl, which are thicker than 10 mm, due to shrinkage of the nutrition area from 2.5×2.5 to 1.5×1.5 m. Close and distinct correlation ($P<0.001$) has been established between the number of branches on the stem at the height from 1 to 2 m, the diameter of a tree and initial density.

With increasing height from the ground surface the number of branches in a whorl diminishes whilst the diameter of all branches and the thickest ones enlarges. Due to an increase in the height from 1.5 to 3.5 m from the ground surface the number of branches in a whorl in the plantations of different initial density decreases from 0.4 to 2.0 whereas due to an increase in the height from 3.5 to 5.5 m the number of branches in a whorl diminishes from 0 to 0.6. An increase in the height from 1.5 to 5.5 m from the ground surface results in enlargement of the mean diameter of the thickest branches from 4 to 9 mm and the mean diameter of branches from 3 to 6 mm. While investigating pine plantations Persson (1977) and Lehtonen (1978) have determined that with increasing height the thickness of branches in the lower part of the stem increases and in the upper part diminishes. The thickest live branches are found in the lower part of a crown because they are oldest (Petersson 1997).

Wood basic density increases from the core towards the external part of the stem. The initial density and the diameter of a tree exert no influence on this regularity. Physical properties of wood in the central part of the stem, which is formed from so called juvenile wood, differs from these in the external part of the stem, which is formed from so called mature wood. The level of mature wood basic density is used as a quality indicator of wood in assessing the influence (Madsen et al. 1978, Moltesen et al. 1985) of economic activity in the forest. Olesen (1977) has determined that in the stem of Norway spruce from the core towards the external part minimal wood basic density is near the 8^{th}-10^{th} tree rings. Similar results have been obtained by Danborg (1994), Noren, Stähl (1996) and Pape (1999). Wood density increases towards the external part of the stem and the level of mature wood is attained near the 15^{th}-25^{th} tree rings (Olesen 1977). In accordance with the data obtained by Danborg (1994) the boundary between juvenile and mature wood is near the 10^{th} tree ring.

Juvenile wood basic density in the plantations with different initial density was similar and no dependence on the initial density was observed. The most significant mature wood density was found by us in the plantations where the initial density was 1,970 and 3,010 seedlings ha^{-1}, i.e. wood basic density augmented due to an increase in the initial density up to 1,970 and 3,010 seedlings ha^{-1}. However, due to a further increase in the initial density of plantations the density of wood started diminishing. Statistically reliable ($P<0.05$) differences were only between the plantations with the initial density 1,970 seedlings ha^{-1} and these with the initial density 820 and 12,500 seedlings ha^{-1}. Johansson (1993) determined that in the plantations with the initial density 1.5×1.5 m wood basic density was reliably higher than in thinner plantations. An increase in wood basic density of spruce, which results from an increase in the initial density, was determined by Persson (1975).

Moltesen et al. (1985) investigated the plantations of square distribution where the initial density (from 0.5×0.5 to 2.5×2.5 m) was different. They have determined the difference between wood basic density in plantations at initial density 0.5×0.5 m and in other density variants. In the opinion of the authors this influence is attributed to the variability of quality class in different density variants.

The obtained data corroborate the inference by Johansson (1993) that the initial density exerts an intangible influence on wood basic density, which in practice is insignificant.

Reliable and close correlation ($P<0.001$) exists between the diameter of a tree and wood basic density. Trees (relative diameter 1.0-1.2) with the mean diameter and these with slightly larger diameter than the mean one are characteristic of the highest wood basic density. These are the trees of class A and B and the trees which transfer from class to class and which are submitted to hardly noticeable suppression by neighbouring trees (Kairiūkštis 1973). Wood density of both thinner and thicker trees, i.e. I and IV class after Kraft and class A[1] and C after the above author, is less. It corresponds to the results obtained by Nylinder (1953) that the highest wood basic density is typical of trees of average measurements. It must be noted that similar conclusions were made in the 1950's at the Lithuanian Forest Research Institute while investigating physical mechanical properties of wood for black alder and pine on the basis of site quality. In stands of II site quality wood of pine and black alder had the highest basic density. While statically bending, bending by blow and crushing it the indexes were highest (Jonaitis 1958, Stinskas 1959). Hilderbrant (1954) has also determined that trees, the growth of which is slowest, have the least wood basic density. In accordance with the data by Johansson (1993), Lindstrom (1996) and Pape (1999) slowly growing trees have the highest wood basic density whilst the dominating trees lowest. It partly contradicts the results obtained by us. Inadequacy of the obtained results has been apparently induced due to investigation of thinned and unthinned plantations with different initial density. Significant density crucially affects the appearance of slowly growing trees with narrow crowns. Such trees first use the products of photosynthesis for breathing, for the branch, needle and height increment but these products are insufficient for the diameter increment (Assmann 1970; Oliver and Larson 1996). The second reason for it is that during thinning the average height and diameter of the plantations are artificially changed and the trees which were characterized as average prior to thinnings may become slowly growing trees following them.

The characteristics of wood fibre depend upon the conditions of tree growth. There is close correlation between the magnitude of photosynthesis production and the thickness (Larson 1969) of cellular walls. With increasing initial density, i.e. with worsening conditions of the growth of tree crowns and at the same time with decreasing magnitude of photosynthesis production tracheid length, the diameters and cellular wall thickness (Davletšina 1990) diminish. Under the effect of high density the thickness of cellular walls relatively decreases more considerably than their length and diameters. This is the main reason crucially affecting less wood basic density of slowly growing trees or these growing in plantations with significant initial density. In our experiments the ratio of late to early wood was found to be highest in plantations with average density or average trees within a density variant. In comparison to early wood, the thickness of cellular walls of late wood is larger twice. The ratio of late to early wood of dominating trees growing in a stand or in plantations with insignificant initial density appeared to be least. The ratio of late to early wood of slowly growing trees or trees growing in plantations with significant initial density is less than that of average trees. The ratio of late to early wood, evidently, determines less wood basic density and is one of the reasons for the level of wood basic density of slowly growing trees or trees growing in plantations with significant initial density.

Conclusions

1. The thickness of branches, their number per length unit of a stem and in a whorl and the extent of stem taper towards the top diminish due to an increase in the initial density. In case the initial density increases up to 12,500 seedlings ha^{-1} stem straightness augments. However, due to a further increase in the initial density stem straightness diminishes. With increasing height from the soil surface the number of branches in a whorl decreases and their thickness enlarges in all density variants.

2. Wood density depends upon the initial density of plantations and upon the diameter of a tree in the stand; the highest wood density is observed in case the initial density of plantations is 2-3 thousand seedlings ha^{-1} and in case the stem slightly exceeds (1.0-1.2) the relative diameter.

3. High and distinct correlation ($P<0.01$-0.001) has been established between the initial plantation density and the diameter of a tree, the height from the soil surface up to the first live branch, the number of branches on the stem near the ground (1-2 m) and the diameter of the thickest branch. Also high and distinct

correlation ($P<0.001$) is between the diameter of a tree and height from the ground surface up to the first live branch, the number of branches on the stem near the ground (1-2 m), the diameter of the thickest branch and wood basic density.

4. The initial plantation density (about 2,000 seedlings ha^{-1}) ensures high stand productivity, which is close to the maximum, technically acceptable stem straightness and the extent of stem taper and the highest wood basic density. However, due to the above initial density the quality class of the butt logs (5.0 m) is worsened by thick (^{3}2 cm) branches occurring in many (78%) trees. In plantations with higher initial density (3,000 seedlings ha^{-1}) the stems with branches ^{3}2 cm thick comprise only 23%. Stands with such density are typical of more significant straightness of stems and higher quality class of butt logs. Therefore, the initial density about 3,000 seedlings ha^{-1} in spruce plantations of square distribution is advantageous.

5. The regularities have been found, which concern the dependence of the diameter of a tree, the number and thickness of branches, straightness and form of stems, wood basic density on the initial plantation density. They corroborate the standard regulating density, which is, currently, applied to thinning in Lithuania as well as the principles of selecting trees for felling when in carrying out the first thinning, along with slowly growing, damaged, crooked, multitop trees with thick branches and wide crowns, trees of very intensive development (A^1) and suppressed (class C) trees are felled. The stands are formed under the regime of the growing of maximally productive forests.

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ВЛИЯНИЕ НАЧАЛЬНОЙ ГУСТОТЫ КУЛЬТУР ЕЛИ (*PICEA ABIES* KARSTEN) НА КАЧЕСТВО ДРЕВЕСИНЫ

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Резюме

Изучались 39-летние культуры ели различной первоначальной густоты (820, 1970, 3010, 6500, 12500, 25000, 50000 и 100000 шт га$^{-1}$) с квадратным размещением посадочных мест, растущие в Дубравском экспериментальном лесном предприятии. Культуры созданы на сплошь обработанной почве двухлетними сеянцами местного происхождения. Рубки ухода в культурах не проводились. Установлено, что начальная густота культур имеет существенное влияние на сбег и прямизну стволов, количество ветвей в мутовке и на отрезке стволов на высоте от 1 до 2м, а также на соотношение ширины годичных колец поздней и ранней древесины. При увеличений начальной густоты культур от 820 до 12500 шт га$^{-1}$ прямизна стволов увеличается, а при дальнейшем увеличении начинает уменьшаться. При увеличении начальной густоты культур уменьшается как средний диаметр всех ветвей так и наиболее толстых ветвей. Увеличение начальной густоты культур до 1970 шт га$^{-1}$ не влияет на качество ветвей ни в мутовке, ни на упомянутом отрезке ствола, а при увеличении начальной густоты от 1970 до 12500 шт га$^{-1}$ количество ветвей в мутовке уменьшается на 28-33%. При увеличении высоты мутовки от 1,5 до 5,5 м от поверхности земли количество ветвей в мутовке уменьшается, а средний диаметр их увеличивается.

Начальная густота культур оказала статистически достоверное влияние на ширину годичных колец, соотношение поздней и ранней древесины, а также на плотность древесины.

Ключевые слова: ель обыкновенная, начальная густота культур, количество ветвей, прямизна стволов, плотность древесины.