The Influence of the Initial Density and Site Conditions on Scots Pine Growth and Wood Quality

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Trials established to test various initial density of Scots pine under *Vacciniosa*, *Vaccinio-myrtillosa* and *Oxalidosa* site conditions were studied.

It was found that the initial stand density influenced stem straightness, branch thickness and branch number in a whorl as well as resistance to diseases and climatic factors. However, the initial density had no influence on basic wood density and early-/late-wood ratio. At the test trials of the same initial density that were established under fertile site conditions, the pines had more curvy stems, thicker branches and more branches in a whorl. Despite basic wood density and early-/late-wood ratio were not dependent on the initial stand density, these traits were influenced by site conditions and tree position in the stand. The lowest and the highest basic wood density was observed for the trees having lowest growth rate and having relative diameter of 1.1 - 1.4, respectively. Productive and sustainable Scots pine stands are ensured when planting 3 - 8 thou. seedlings/ha. An exact initial stand density within these limits should be chosen according to the wood quality desired and economical conditions. Variation in stem straightness, branch thickness, branch number in a whorl and wood basic density among individual trees was high, therefore, for a seek of improved wood quality, tree selection in the stand ought to be performed by quality traits. The seedlings having desirable genetic features should be used for reforestation purposes too.

Key words: Scots pine test trials, initial stand density, growth, wood quality

Introduction

After the Lithuanian forest enterprises started international trade, the timber quality received a major importance. There are publications indicating that wood quality to some extent is influenced by initial stand density. Jiang Hong (1990) stressed that the initial stand density was one of the major factors influencing the parameters of the future stands. However, the climatic conditions should be considered too.

Forest plantations besides performing other duties, are established for wood purposes. However, the wood of some certain technical properties is required but not generally wood. The grading of logs and boards (Persson, 1977) and the structural performance of wood (Danberg,1994) are influenced by wood density, annual ring width and the number and diameter of branches. Wood technical properties in some extent might be influenced by sylvicultural methods because these properties are in relation with growth rate and competition among the trees. It has been found that the diameter of the thickest living branch correlated closely with the stem diameter near this branch, the diameter of the thickest living branches decreases from crown base and upwards (Petersson, 1998), the height to first living branches diminish with increasing spacing, the stems selected in close spacing are straighter than these from wide spacings, the influence of spacing on the number of branches per whorl does not seem to be strong (Persson, 1977), the distance between the whorls and number of knots per whorl both increased with increasing site index (Bjorklund, 1997), the diameter of the thickest living branch of a tree was linearly dependent on the dbh (Salminen and Varmola, 1993), the diameter of the thickest branches tended to increase more rapidly than the mean branch diameter when the tree diameter increased (Kellomaki and Vaisanen, 1986). Besides the mentioned results, many other trends were found too. However, the influence of the initial trial density on Scots pine wood quality had not been studied in Lithuania yet. Such studies performed in abroad suggest that there were relationships among initial density and stem straightness, branch thickness, branch number in a whorl, basic wood density, etc. However, the exact figures for the Lithuanian conditions remained unknown. The aim of this investigation was to study Scots pine growth and wood quality in the test trials of various initial density that were established under *Vacciniosa*, *Vaccinio-myrtillosa* and *Oxalidosa* site conditions.

Materials and methods

The Scots pine test trials of various density in question were established in the forestry districts Ežerėlis and Vaišvydava of the Dubrava experimental-training forest enterprise (ETFE) and Tiltai forest district of the Valkininkai forest enterprise (Table 1). The trials were established in entirely prepared soil by planting one year old seedlings that were grown up from the local seeds. In Ežerėlis, Vaišvydava and Tiltai forest districts established blocks were as large as 0.20, 0.10 and 0.80 - 1.20 ha, respectively. No thinnings except these eliminating naturally regenerating birch and pine seedlings were performed. Tree height and breast height diameter (DBH) were assessed as well as technical stem quality was evaluated and branch thickness was measured. Stem straightness was scored from 1 to 5 with straight stems assigning a score of 1 and with unsuitable stems (according to the technical requirements TS - 2006102 - 1 – 93) assigning a score of 5.

Table 1. Characteristics of the trials with various density of trees.

Place	Site	Age, years	Initial density
Dubrava ETFE Ežerėlis forest district	*Vacciniosa*, H_{100}-27.0	20	500 3,000 4,440 8,000 15,000 25,000 50,000 100,000 200,000
Valkininkai forest enterprise Tiltai forest district	*Vaccinio-myrtillosa*, H_{100}-29.0	32	6,700 9,800 13,300 20,000
Dubrava ETFE Vaišvydava forest district	*Oxalidosa*, H_{100}-31.0	38	3,300 5,000 6,670 8,000 10,000

Besides, the number of stem bows was calculated and the presence or absence of double top was determined as well. Within each block of different density, 50 trees were selected randomly to whom branch thickness was evaluated in a tree height between 1 and 2 metres. Branch diameter was measured perpendicularly to the branch axis at the distance of 30 mm from the stem. The height to the first green branch and crown length were assessed too.

In each block of various density, 20 trees were selected systematically-randomly according to their distribution by diameter. They were used for wood sampling Presler's drill. Later, the width of early- and latewood rings and basic wood density were evaluated.

$$\textit{Basic wood density} = \frac{\textit{weight of totally dry wood}}{\textit{volume of fresh wood}}$$

Wood volume was computed after measuring length (precision of measurements 0.1 mm) and diameter (precision 0.001 mm) of wood sample that was previously soaked in ethyl alcohol. The possible maximum deviation when computing wood volume should not exceed 4%. Wood samples were weighed after drying at 105° C (precision 0.0001 g.).

The trials of various density were established at both forest enterprises using the seed of local, thus, differing origin. Therefore, the variation in stem quality traits was evaluated at the trials that were established by Dr. V.Ramanauskas and that consisted of trees of both origins. The latter two trials were established under considerably differing *Vacciniosa* and *Oxalidosa* site conditions. Stem quality traits (Table 2) in these trials were evaluated for the families Dubrava (family No. 401), Labanoras (No. 503) and Latežeris (No. 522) which is situated closely to Valkininkai. Labanoras origin was evaluated for a seek of comparison with the other origins. The trials were established in five replications. The data presented in Table 2 were taken into consideration when analysing stem quality traits evaluated at the trials of various density that were established in Dubrava and Valkininkai forest enterprises.

Table 2. Stem quality data

Trait	*Vacciniosa* site			*Oxalidosa* site		
	Family No.			Family No.		
	401	503	522	401	503	522
Mean branch diameter, mm	9.7	9.2*	9.7			
Mean diameter of the thickest branches, mm	16.2	16.2	20.6*			
Branch number in a whorl	6.7	7.1*	6.6	9.5	9.3	9.7
Stem straightness, points	1.5	1.5	1.2*	1.8	1.9	1.9

* - differences between clones are significant at P<0.05 level.

Results

Trial characteristics

Survival

Mean survival at 3-year-old trials that were established under *Vacciniosa* and *Occalidosa* site conditions reached 99-92% and 96-86%, respectively (Table 3). In accordance with the data by Dingelis (1975), the survival at the trial which was established under *Vaccinio-myrtillosa* site conditions comprised 87-72%. During the first several years after establishing, the survival at the trials was not influenced by the initial density at any of the sites.

Table 3. Course of self-thinning (percentage of dead trees over the age period) of trees.

Initial density, trees/ha	Age period, years						Survival of trees aged 15 years	Survival of trees at the time of evaluation
	0-3	3-6	6-10	10-14	14-17	17-20		
Vacciniosa site								
500	0.8	0	0	0	0	0	99.2	99.2
3,000	2.1	14.9	0.3	3.7	3.0	3.0	78.7	75.3
4,440	1.3	23.5	3.4	8.8	6.0	4.1	63.4	58.1
8,000	3.1	25.1	18.3	17.0	5.4	2.6	47.9	45.4
15,000	5.6	30.6	7.6	33.3	10.6	8.6	38.2	33.6
25,000	4.5	29.9	28.9	7.9	33.1	15.6	35.9	24.7
50,000	5.5	40.2	18.6	2.6	48.6	16.1	33.8	19.5
100,000	1.8	69.8	19.1	2.9	47.6	23.0	17.9	9.4
200,000	8.4	87.1	27.2	0.3	43.0	13.6	6.6	6.0
Oxalidosa site								
3,330	4.5	0	0.5	9.6			85.9	42.9
5,000	6.8	0	5.7	17.1			76.8	34.8
6,670	11.4	0	4.7	12.8			71.8	26.8
8,000	14.0	0	6.7	12.5			69.0	23.0
10,000	11.3	0.3	10.5	14.8			68.7	15.0
20,000	7.8	0.2	11.7	17.5			64.0	
40,000	13.5	0.5	14.5	19.4			56.5	

As seen from the presented data, the highest and the lowest survival was observed under *Vacciniosa* and *Vaccinio-myrtillosa* site conditions, respectively. In accordance with the forest inventory data in Lithuania in 1996-98, the 3-year-old pine's survival under *Vacciniosa*, *Vaccinio-myrtillosa* and *Occalidosa* site conditions constituted 78.3, 83.8 and 76.1%, respectively.

In the trials established under *Vacciniosa* site conditions in 1979 and 1980, pines were injured by *Lophodermium pinastri*. In 1980, the intensity of pine damage was evaluated. It was found to be strongly influenced by the initial density (Table 4). An increase in the initial density from 4,440 trees/ha to 100,000 trees/ha resulted in increased damage by *Lapodermium pinastri* too. The differences in damage intensity among the blocks of various initial density were statistically significant at $P<0.01$ level. The mean damage point at the trials of lower initial density (500, 1,000, 2,000 trees/ha) was close to one at the trial of 3,000 trees/ha. The damage point at the trials of 100,000 and 200,000 trees/ha density was almost equal (2.50 and 2.49, respectively).

Table 4. *Lapodermium pinastri* damage intensity at 5-year-old trials of various initial density.

Initial trial density, trees/ha	Non-damaged or weakly damaged, %	Intermediately damaged, %	Strongly damaged or dead, %	Mean damage point
3,000	48	30	22	1.47
4,400	45	34	21	1.76
8,000	35	42	23	1.88*
15,000	19	51	30	2.11*
25,000	16	33	51	2.35**
50,000	9	39	52	2.43**
100,000	12	26	62	2.50**
200,000	14	23	63	2.49

*, ** - differences are significant at $P<0.05$ and $P<0.01$ level, respectively.

Due to the damage by *Lapodermium pinastri*, survival at the trials of high initial density decreased considerably (Table 3). At the trial age of 6 years, the highest and the lowest survival was observed at the most sparse (99%) and the most dense (17%) trials, respectively. Further self-thinning took place due to too high trial density as well as because of random reasons. At the trial age of 20 years, survival varied from 99% (planting density was 500 trees/ha) to 6% (planting density was 200,000 trees/ha).

Self-thinning at the trials of high density was not even, i.e. the periods of low self-thinning intensity were followed by the periods of high self-thinning intensity. The first period of high self-thinning intensity took place in all the trials of each initial density (with exception of the trials of 500 trees/ha) at the age of 4 - 6 years. This period was influenced by the damage of *Lapodermium pinastri*. The second period of high self-thinning intensity occurred at 10 - 14 year old trials of 15,000 trees/ha density and at 6 - 10 and 14 - 17-year-old-trials of 25,000 trees/ha and higher density.

Self-thinning due to too high density of the trial established under *Oxalidosa* site conditions started at age of 6 - 10 years and gradually increased until the trial reached the age of 15 years. The survival at the 15-year-old trial established under *Oxalidosa* site conditions was 8-27% higher than the survival at the trial of the same initial density that was established under *Vacciniosa* site conditions. The 18-year-old trials of 13,300 trees/ha and higher density that were established under *Oxalidosa* site conditions were destroyed by snow-breaks. The trial of 10,000 trees/ha density that was established under the same site conditions was considerably damaged by snow-breaks too while the trials of 8,000 trees/ha and lower density showed almost no damage due to snow-breaks.

However, the trials of 10,000 trees/ha and higher density that were established under *Vacciniosa* and *Oxalidosa* site conditions, were damaged by pine root fungus *Fomitopsis annosa*. Most of the trials where this damage was observed were 10 years of age. However, at the trials of very high initial density (50,000 trees/ha and more) this damage had already occurred at the age of 7 - 8 years. The trials of 9,800 trees/ha and higher density that were established under *Vaccinio-myrtillosa* site conditions were damaged by *Fomitopsis annosa* as well.

Table 5. Growth characteristics at the trials

Initial trial density	Whole stand					500 thickest trees		
	D, cm	H, m	D/H	EG, m^2	V, m^3	D, cm	H, m	D/H
Vacciniosa site. 20-year-old trial.								
500	12.4	7.2	172	6.0	32	12.4	7.2	172
3,000	8.4	7.2	117	12.4	66	12.5	8.3	151
4,440	8.2	7.4	111	13.7	73	12.9	8.7	148
8,000	6.6	6.9	96	12.3	75	12.7	8.4	151
15,000	6.6	6.3	105	18.1	85	11.4	8.3	137
25,000	5.2	5.5	94	13.0	67	10.4	7.5	139
Vaccinio-myrtillosa site. 32-year-old trial.								
6,670	13.1	14.0	94	31.0	243	18.2	15.1	120
9,800	13.1	14.1	93	31.3	252	18.5	15.8	117
13,300	12.1	14.3	85	29.7	238	17.2	14.8	116
20,000	11.3	13.5	84	29.2	227	16.7	15.0	107
Oxalidosa site. 38-year-old trial.								
3,330	18.1	18.5	92	36.8	380	23.7	21.1	112
5,000	16.8	18.6	90	38.6	380	21.1	21.2	100
6,670	16.4	17.8	92	37.6	364	21.8	21.0	104
8,000	16.7	18.6	90	40.3	402	22.6	21.8	104
10,000	15.2	17.8	85	27.2	264	19.2	19.8	97

Growth characteristics

The initial trial density had also influence on the mean diameter and height at the trials established under all site conditions (Table 5). The mean diameter of the stand gradually decreased when the initial density increased. Comparing the 20-year-old trials of 25,000 and 500 trees/ha density that were established under *Vacciniosa* site conditions, it was found that the mean diameter was 2.4 times larger at the trial of lower initial density. At the older trials that were established under more fertile site conditions these differences are smaller. The initial density had much lower influence to the mean height rather than to the mean diameter. Height differences between the trials established under both *Vaccinio-myrtillosa* and *Oxalidosa* site conditions were statistically non-significant. The initial trial density of 500 - 8,000 trees/ha at the trials that were established under *Vacciniosa* site conditions had non-significant ($P>0.05$) influence on height as well. Similarly to the mean diameter, the mean height of the stand decreased when the initial density increased.

The initial density had much smaller influence on diameter and height of 500 thickest trees rather than on these traits of all the estimated trees. At the trials that were established under *Vacciniosa* site conditions, the mean diameter of 500 thickest trees increased when the initial density was increasing from 500 to 8,000 trees/ha. At even higher initial density, the mean diameter of 500 thickest trees started to diminishing. The same trend was observed at the trials that were established under *Vaccinio-myrtillosa* and *Oxalidosa* site conditions as well. At the trials established under *Vacciniosa* site conditions, the smallest (7.2 meters) and the largest (8.7 metres) mean height of 500 thickest trees was observed at the trials of 500 trees/ha and 4,440 trees/ha density, respectively. Further increasing initial density resulted in gradually decreasing mean height of 500 thickest trees. The mean heights of 500 thickest trees at the trials that were established under *Vaccinio-myrtillosa* and *Oxalidosa* site conditions differed insignificantly from each other.

When the initial trial density was increasing, the diameter/height (D/H) ratio decreased at the trials established under all site conditions. The D/H ratio of 500 thickest trees was considerably higher than that of intermediate trees. By comparing two trials of the same initial density and height it was observed that the D/H ratio was considerably lower at the trial that was established under *Vacciniosa* rather than under *Oxalidosa* site conditions (Fig. 1).

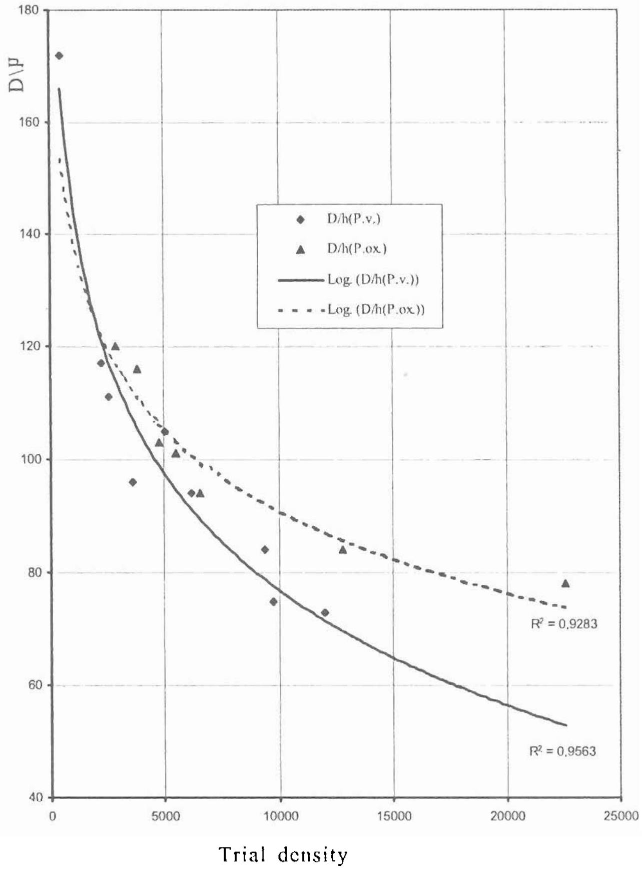

Figure 1. The influence of Scots pine trial density under *Vacciniosa* and *Oxalidosa* site conditions on tree diameter/ height ratio.

At the trials that were established under *Vacciniosa*, *Vaccinio-myrtillosa* and *Oxalidosa* site conditions, the highest sum of basal area and the highest stem volume were recorded at the trials of 15,000, 9,800 and 8,000 trees/ha initial density, respectively.

Stem and wood quality

Stem quality

Both initial trial density and site conditions had influence on stem and wood quality. Stem quality was determined by evaluation of double top, i.e. top exchange in a tree height between 1 and 2 metres, number of stem bows and stem straightness were examined. It was found that presence of double top was influenced neither by initial trial density nor by soil fertility (Table 6). Most of the double tops were observed in the trials of Valkininkai forest enterprise and probably they were stimulated by shoot moth damage. When increasing initial density or decreasing soil fertility, the number of stem bows decreases and, thus, stem straightness increases.

Differences in the number of stem bows or stem straightness among the trials of 500 and 4,400 trees/ha

Table 6. Stem quality at the trials of various density.

Initial trial density	Forked		Number of bows		Stem straightness	
	M	±m	M	±m	M	±m
			Vacciniosa site			
500	0.10	0.04	1.00	0.12	1.90	0.12
3,000	0.08	0.04	0.83*	0.14	1.73	0.11
4,440	0.08	0.04	0.58*	0.11	1.52*	0.11
8,000	0.06	0.03	0.69*	0.12	1.47*	0.08
15,000	0.09	0.04	0.36*	0.10	1.28*	0.07
25,000	0.07	0.03	0.63*	0.09	1.30*	0.07
			Vaccinio-myrtillosa site			
6,700	0.20	0.06	1.16	0.15	1.88	0.11
9,800	0.34	0.07	0.90	0.12	1.86	0.14
13,300	0.22	0.06	0.68	0.13	1.76	0.10
20,000	0.46	0.23	0.94	0.15	1.76	0.13
			Oxalidosa site			
3,330	0.14	0.05	0.67	0.11	1.82	0.12
5,000	0.80	0.04	0.67	0.11	1.65	0.11
6,670	0.10	0.04	0.63	0.13	1.49*	0.10
8,000	0.08	0.04	0.73	0.12	1.62	0.11

* - differences are significant at $P<0.05$ level

and higher density that were established under *Vacciniosa* site conditions were statistically significant ($P<0.005$). Comparing the trials that were established under *Oxalidosa* site conditions, the differences in stem straightness were statistically significant only among the blocks of 3,330, 6,670 and 10,000 trees/ha density. The lowest number of stem bows and the straightest stems were observed at the trials of 15,000 and 10,000 trees/ha density that were established under *Vacciniosa* and *Oxalidosa* site conditions, respectively. At the trial which was established under *Vaccinio-myrtillosa* site conditions, the number of stem bows and stem straightness were influenced much more considerably by frequently repeating top exchanges.

Branch number and thickness

Branch number in a whorl depends both on the initial density and site conditions although influence by site conditions is much larger than that by initial density (Table 7). Branch number in a whorl decreased gradually when the initial density was increasing. Comparing the trials that were established under *Vacciniosa* site conditions, the differences in branch number in a whorl were statistically significant ($P<0.05$) when com-

Table 7. Mean stand branch number in a stem unit of 1 meter length and in a whorl.

Trial initial density, trees/ha	Branch number in a tree height between 1 and 2 metres		Branch number in a whorl	
	M	±m	M	±m
Vacciniosa site				
500	16.0	0.75	6.5	0.21
3,000	17.5	0.66	6.6	0.19
4,440	16.5	0.63	7.2	0.24
8,000	16.9	0.49	6.3	0.14
15,000	17.0	0.64	6.0*	0.17
25,000	16.7	0.57	6.1*	0.18
Vaccinio-myrtillosa site				
6,670	17.5	0.77	6.2	0.24
9,800	16.1	0.67	5.8	0.23
13,300	16.1	0.74	5.5*	0.24
20,000	17.7	0.76	5.6*	0.20
Oxalidosa site				
3,330	13.7	0.62	8.0	0.21
5,000	13.8	0.61	8.0	0.23
6,670	13.7	0.58	7.7	0.24
8,000	13.4	0.68	7.1*	0.27
10,000	12.5	0.55	6.6*	0.24

* - differences are significant at P<0.05 level.

paring the trials of 500 and 3,000 trees/ha density on one side with the trials of 15,000 trees/ha and higher density on the other side. At the trials that were established under *Vaccinio-myrtillosa* site conditions, statistically significant differences in branch number in a whorl were found when comparing the trials of 13,300 trees/ha and higher density with the trial of 6,670 trees/ha density. The same trend was observed when comparing the trials of 8,000 trees/ha and higher density with the trial of 3,330 trees/ha density that were established under *Oxalidosa* site conditions. The differences in branch number in a whorl were also statistically significant (P<0.05) when comparing the trials established under *Vacciniosa* and *Vaccinio-myrtillosa* site conditions on one side and under *Oxalidosa* site conditions on the other side. There were more branches in a whorl observed at the trials that were established under more fertile site conditions rather than at the trials established under poor site conditions.

Despite branch number in a whorl was higher at the trials that were established under fertile site conditions, the total branch number in a stem unit of 1 meter length was higher at the trials established under poor site conditions. By comparing the trials of the same density that were established under different site conditions, it was observed that the total branch number in a stem unit of 1 meter length was higher in 3 - 4 units in the trial which was established under *Vacciniosa* site conditions than in that established under *Oxalidosa* site conditions (Table 7).

The difference in total branch number in a stem unit of 1 meter length among the trials that were established under the above mentioned site conditions was statistically significant at P<0.01 level. However, the total branch number in a stem unit of 1 meter length was not influenced by the initial trial density.

At the trials of 500 trees/ha initial density, both dead and green branches were measured when evaluating branch thickness while only dead branches were assessed at the trials of higher initial density. In a stem unit of 1 meter length estimated mean branch diameter and diameter of the thickest branches were influenced by both initial density and site conditions (Table 8). The

Table 8. In a stem unit of 1 meter length estimated mean branch diameter (D mean) and diameter of the thickest branches.

Initial density, trees/ha	D mean, mm		Mean diameter of the thickest branches, mm	
	M	±m	M	±m
Vacciniosa site				
500	20.7	1.76	39.0	1.93
3,000	13.4**	0.37	21.8**	1.10
4,440	12.6**	0.89	22.8**	0.74
8,000	12.5**	0.85	20.3**	0.86
15,000	11.0**	0.51	17.3**	1.06
25,000	9.6**	0.59	14.7**	0.20
Vaccinio-myrtillosa site				
6,670	13.4	0.25	24.4	0.80
9,800	13.0	0.26	23.7	1.06
13,300	11.6*	0.21	20.5*	0.66
20,000	11.0**	0.18	19.3**	0.75
Oxalidosa site				
3,330	15.8	0.30	27.0	0.60
5,000	14.9*	0.30	27.0	0.59
6,670	12.0**	0.91	24.5*	0.55
8,000	12.8**	0.28	23.8**	0.48
10,000	13.1**	0.24	21.9**	0.44

* and ** - significant at P<0.05 and P<0.01 level, respectively.

branches in a stem unit were thinner at the trials of higher density or under less fertile site conditions. Both trial initial density and soil fertility influenced in a stem unit estimated the mean diameter of the thickest branches more than the mean branch diameter. By comparing the trials of the same initial density that were established under *Vacciniosa* and *Oxalidosa* site conditions, it was found that the differences in a stem unit estimated mean branch diameter and mean diameter of the thickest branches were statistically different between these trials at P<0.05 and P<0.01 level, respectively. By comparing the trials of the same initial density it was found that the mean diameter of the thickest branches in a stem unit was lower in 2 - 5 mm at the trial that was established under *Vacciniosa* site conditions than at the trial established under *Oxalidosa* site conditions. Assuming that the course of self-thinning at different trials was the same, the indicated differences in branch thickness in a stem unit might be even more considerable as self-thinning process at young age was more intensive at the trials that were established under *Vacciniosa* site conditions than at the trial established under *Oxalidosa* site conditions.

In a stem unit estimated the mean branch diameter as well as the mean diameter of the thickest branches was influenced by tree diameter. These traits of the thicker trees were larger than the traits of thinner trees (Fig. 2). Moreover, in a stem unit estimated the mean branch diameter increased more rapidly when the tree diameter increased than the mean branch diameter did.

In a stem unit of 1 meter length estimated the mean branch diameter and mean diameter of the thickest branches were evaluated for 500 thickest trees as well as stand mean was calculated. It was found that these traits that were estimated for 500 thickest trees exceeded one computed on the basis of stand (Table 9). The mean branch diameter of the thickest trees exceeded the branch diameter of the stand in 0.3 - 3.0 mm. Similarly, the mean diameter of the thickest branches was higher than mean diameter of the thickest branches from 0.3 - 6.8 mm. Significant differences in branch diameter were observed at the trials of lower initial density.

By comparing the trials of low or intermediate initial density that were established under *Vacciniosa* site conditions, it was found that the branch number in a whorl estimated for 500 thickest trees and branch number in a stem unit of 1 meter length were larger in 0.6 - 1.2 unit and 1.2 - 1.6 unit, respectively, when comparing with the mean value of the stand (compare Table 7 and Table 10). However, at the trials of higher

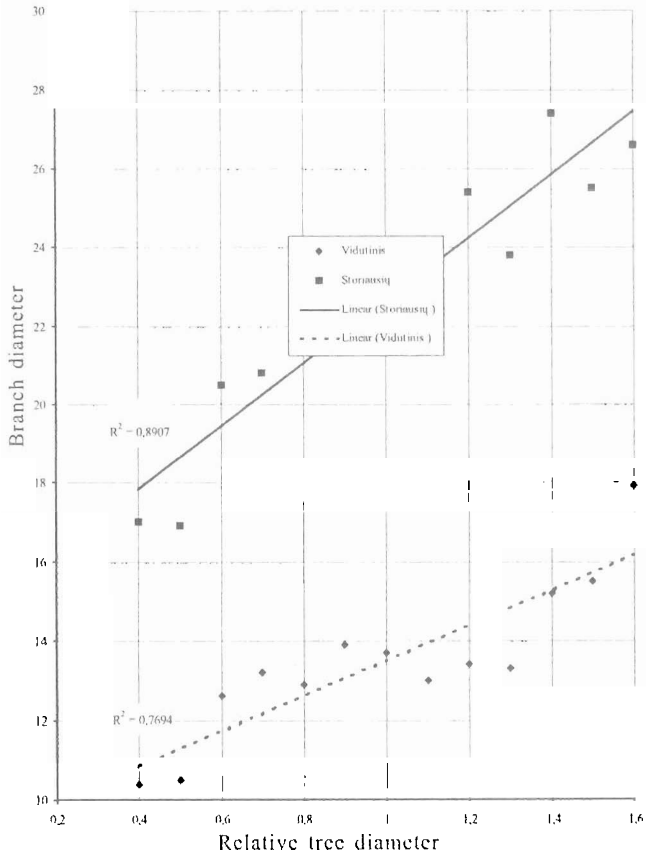

Figure 2. The relationship of relative tree diameter with branch diameter and diameter of the thickest branches at Scots pine trials.

Table 9. For 500 thickest trees estimated mean branch diameter (D mean) and diameter of the thickest branches.

Initial trial density, trees/ha	D mean, mm		D mean of the thickest branches, mm	
	M	±m	M	±m
Vacciniosa site				
500	20.7	1.76	39.0	1.93
3,000	16.6*	0.49	28.6**	1.76
4,440	14.3**	0.36	27.1**	0.94
8,000	16.5*	0.46	20.5**	0.84
15,000	14.8**	0.46	17.6**	0.64
25,000	15.0**	0.64	15.7**	0.76
Vaccinio-myrtillosa site				
6,670	14.6	0.52	28.1	1.20
9,800	15.4	0.54	26.1	1.42
13,300	12.6*	0.47	22.7*	0.73
20,000	12.2*	0.54	23.6*	1.96
Oxalidosa site				
3,330	16.3	0.71	29.7	1.25
5,000	15.2	0.65	27.5	0.85
6,670	15.0	0.69	26.9*	1.29
8,000	13.4*	0.64	25.5*	1.24
10,000	13.3*	0.43	22.5*	0.62

* and ** - significant at P<0.05 and P<0.01 level, respectively.

initial density, branch number in a stem unit was equal or even slightly lower when comparing with the mean value of the stand (compare Table 7 and Table 10).

Table 10. For 500 thickest trees estimated branch number in a whorl and in a stem unit of 1 meter length.

Initial trial density, trees/ha	Branch number in a whorl		Branch number in a tree height between 1 and 2 metres	
	M	±m	M	±m
Vacciniosa site				
500	6.5	0.22	16.0	0.65
3,000	7.8	0.34	19.0	0.71
4,440	8.3	0.37	18.1	0.84
8,000	7.5	0.40	18.1	0.93
15,000	6.9	0.42	17.1	1.01
25,000	6.7	0.37	16.4	0.94
Vaccinio-myrtillosa site				
6,670	6.9	0.35	18.6	0.82
9,800	5.6	0.47	18.0	0.72
13,300	5.8	0.41	17.7	0.89
20,000	5.5	0.39	14.8	0.92
Oxalidosa site				
3,330	8.3	0.38	13.6	1.28
5,000	8.3	0.43	14.7	1.25
6,670	7.0	0.37	12.2	0.88
8,000	6.2	0.50	11.8	1.84
10,000	6.4	0.30	11.8	0.72

At the trials of 3,330 and 5,000 trees/ha density that were established under *Oxalidosa* site conditions, branch number in a whorl as well as branch number in a stem unit of 1 meter length estimated for 500 thickest trees were higher when comparing with the mean of the stand. At the trials of higher density under the same site conditions, an opposite trend was observed, i.e. the mentioned traits were lower when comparing with the mean value of the stand. It was also found that at the trials that were established under *Vaccinio-myrtillosa* site conditions, both branch number in a whorl and branch number in a stem unit estimated for 500 thickest trees were close to the mean value of the stand (compare Table 7 and Table 10).

In accordance with the technical requirements TS - 2006102 - 1 - 93, the largest branch diameter (with exception of rotten knots) which is still allowed for saw-logs and veneer-logs of the first sort is 30 mm. At the trials that were established under *Vacciniosa*, *Vaccinio-myrtillosa* and *Oxalidosa* site conditions, the branches up to 30 mm of diameter were found when the initial density was up to 8,000 trees/ha, 20,000 and 10,000 trees/ha, respectively. However, occurrence of 30 mm and larger branches at the trial of 3,000 trees/ha density which was established under *Vacciniosa* site conditions was accidental and should be attributed to absence of the neighbouring trees or exchange of the top (Fig. 3). Occurrence of 30 mm and larger branches at the trials that were established under *Vaccinio-myrtillosa* and *Oxalidosa* site conditions was accidental when the initial density was 13,300 and 5,000 trees/ha, respectively. Occurrence of 30 mm and larger branches at the trials of high initial density that were established under *Vacciniosa* site conditions was determined by frequent top exchange and seedling origin. A whorl was formed of 3 - 4 thick and several thin branches when the trials were established by use of Valkininkai and Latežeris origins (Table 2) while the pines of Dubrava origin were characteristic at the whorl formed of branches that were of more equal diameter.

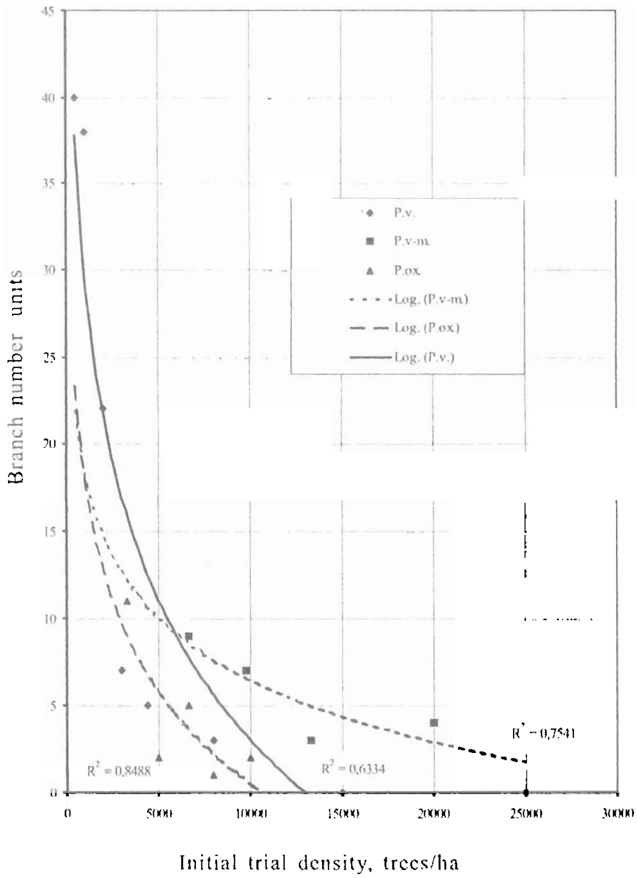

Figure 3. The relationship of initial trial density with number of branches of 30 mm diameter and thicker in a stem unit of 1 meter length.

Correlation coefficients of the relationships between various quality traits are given in Table 11. The correlations between tree height and height to green branch as well as between branch number in a whorl and stem diameter were weak. However, the correlations between stem diameter on one side and height to green branch, branch number in a whorl, diameter of the thickest branches and initial density are strong and statistically significant ($P<0.01$ - $P<0.001$).

Table 11. Correlation coefficients between different quality traits and initial spacing.

	Diameter	Height to green branch	Branch number in a whorl	Diameter of thickest branch	Relative branch diameter
Height to green branch	R=0.413				
Branch number in a whorl	-0.156	0.158			
Diameter of thickest branch	0.764***	-0.134	0.009		
Relative branch diameter	-0.944***	-0.405	0.770***	-0.872***	
Initial spacing	-0.791***	0.83**	-0.792**	-0.995***	0.505

** and *** - differences are statistically significant at $P<0.01$ and $P<0.001$ level, respectively.

Basic wood density

Basic wood density was not influenced by the initial density of trees in the trial or this relationship was weak. The reason for this might be insufficiently precise methods that were used to estimate basic wood density and that did not allow us to compute the relationships (Table 12).

The highest, slightly lower and the lowest basic wood density was found at the trials that were established under *Vaccinio-myrtillosa*, *Oxalidosa* and *Vacciniosa* site conditions, respectively. The lowest wood basic density was determined in the central part of the stem (close to the pith). It increased gradually in pith - bark direction.

Wood basic density was influenced by tree position in the stand (Fig. 4). The trees of both superior and worst growth had lower basic wood density. The highest basic wood density was reached by the trees having a relative diameter of 1.1 - 1.4. However, there were the trees of both superior and worst growth that had high basic wood density as well. This trait showed high variation at individual tree level.

Late-/early-wood ratio was not dependent on initial trial density but was influenced by site conditions (Table 13).

The ratio was also higher at the trials that were established under more fertile site conditions. Firstly, the late-/early-wood ratio increased gradually in pith - bark direction but later it remained characteristic of the site conditions and varied according to the climatic conditions. The lowest ratio was observed for the trees of worst growth and the highest ratio was reached by the trees having a relative diameter of 1.1 - 1.4 (Fig. 5). However, the trees of superior growth (ones having

Table 12. Wood basic density.

Initial trial density	Period in years when the trees reached a height of 1.3 metres							
	-5		6 - 15		16 - 25		26 -	
	M	±m	M	±m	M	±m	M	±m
Vacciniosa site								
500	352	9.2	398	7.4	400	19.1		
3,000	360	14.5	402	4.4	432	7.9		
4,440	345	9.6	399	6.7	435	11.4		
8,000	336	6.3	388	6.9	438	13.3		
15,000	342	7.6	387	8.2	427	12.1		
Mean	347		395		426			
Vaccinio-myrtillosa site								
6,670	384	7.8	412	6.7	474	8.3		
9,800	385	9.8	409	9.7	437	7.1		
13,300	366	9.3	389	5.6	446	10.6		
20,000	392	13.4	422	8.8	468	12.4		
Mean	382		408		456			
Oxalidosa site								
3,330	358	10.3	413	13.0	459	8.5	523	9.6
5,000	355	8.6	401	9.6	446	11.8	517	8.7
6,670	325	16.6	389	8.0	443	8.1	450	22.4
8,000	376	15.9	419	6.7	457	7.8	499	8.1
10,000	344	7.9	393	9.5	452	8.4	466	13.2
Mean	352		403		451		491	

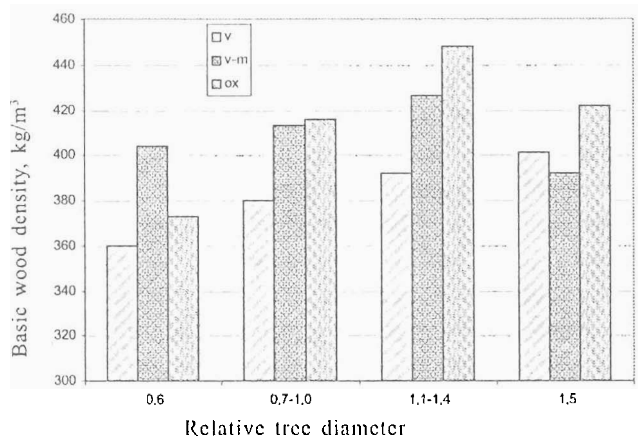

Figure 4. Basic wood density depends on relative tree diameter.

Table 13. Late-/early-wood ratio.

Trial initial density	Period in years when the trials reached a height of 1.3 metres									
	1 - 5	6 - 10	11 - 15	16 - 20	21 - 25	26 - 30	31 - 35	1 - 20	1 - 26	1 - 36
Vacciniosa site										
500	0.23	0.48	0.62	0.57				0.51		
3,000	0.20	0.36	0.64	0.76				0.50		
4,440	0.15	0.41	0.78	0.81				0.56		
8,000	0.20	0.38	0.73	0.75				0.54		
15,000	0.17	0.47	0.67	0.82				0.56		
Vaccinio-myrtillosa site										
6,670	0.44	0.64	0.64	0.70	0.76			0.60	0.64	
9,800	0.25	0.60	0.60	0.64	0.78			0.52	0.58	
13,300	0.44	0.61	0.50	0.76	0.88			0.58	0.65	
20,000	0.40	0.69	0.61	0.73	0.71			0.61	0.64	
Oxalidosa site										
3,330	0.24	0.55	0.65	1.04	0.98	1.07	1.07	0.60	0.72	0.81
5,000	0.20	0.63	0.65	1.00	1.00	1.25	1.01	0.62	0.71	0.82
6,670	0.23	0.52	0.83	1.06	0.95	1.76	1.04	0.64	0.72	0.83
8,000	0.17	0.57	0.65	0.99	0.92	1.03	1.02	0.60	0.67	0.76
10,000	0.13	0.34	0.66	1.02	0.91	0.99	1.04	0.54	0.63	0.74

relative diameter of 1.5 and higher) had a late-/early-wood ratio lower than the trees of 1.1 - 1.4 relative diameter.

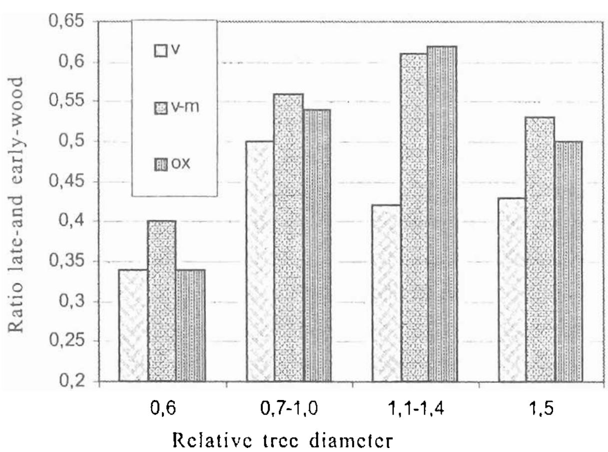

Figure 5. Ratio late-and early- wood depends on relative tree diameter.

Discussion

The influence of the initial density and site fertility on stand parameters, i.e. the mean diameter, tree height and stem volume, is well described in the publications. In this work the obtained results correspond to known trends well. As seen from trial volume as well as mean diameter and height of 500 thickest trees, the initial density of 3,000 - 4,000 trees/ha ensures satisfactory selection of the trees having superior growth and productivity close to the highest stand productivity. Survival up to formation of cenosis was influenced by site conditions but not by the initial density. This result about limited influence of the initial density on survival at the initial growth stage agrees with the findings by Melzer et al. (1992), Salminen and Varmola (1993) and others. The highest Scots pine survival was observed at the trials that were established under *Vaccinio-myrtillosa* site conditions and it was slightly lower under *Oxalidosa* site conditions. When the cenosis has formed, the intensity and character of self-thinning depends on the initial density of pines. At the trials where the initial density of trees is high (15,000 trees/ha and higher), self-thinning begins earlier and proceeds unevenly, i.e. the periods of low self-thinning intensity were followed by the periods of high self-thinning intensity.

In case the initial density is high(10,000 trees/ha and higher) trees are insufficiently sustainable. They are damaged by *Lophodermium pinastri* more intensively, more frequently by pine root fungus *Fomitopsis annosa* and are insufficiently resistant to climatic factors. In accordance with the ratio of the tree diameter to height, the sustainability of non-thinned 20-year-old stands of relatively low initial density (4,440 trees/ha) is decreased considerably (Table 5).

Decreased resistance of trees high or intermediate initial density to pests or diseases is indicated in the publications of other authors as well. Nikolin (1972) had found that in the Arkhangelsk region, the dense Scots pine stands were damaged by *Lophodermium pinastri* much more intensively than sparse stands were. Vuokila (1972) studied Norway spruce stands of various density (1.25 x 1.4; 1.85 x 1.4; 2.0 x 2.0; 2.0 x 2.0; 3.0 x 3.0; 3.0 x 3.5) and found that the number of trees that were damaged by rot decreased when the initial density diminished too (128; 80; 30; 10; 0 and 0, respectively). The butt logs that were damaged by rot made up 60% and 31% at the trials of 10,000 and 1,600 trees/ha initial density, respectively (Johansson and Petterson, 1997). There are also many publications indicating that the trials of low initial density were absolutely or almost absolutely resistant to snow-breaks (Савич et al., 1978; Huuri, 1987; Braadstad, 1979, etc.).

At higher initial density or decreased site fertility, the number of stem bows is less lower as well as stems are straighter. The least number of stem bows and the straightest stems were observed at the trials of 15,000 and 10,000 trees/ha initial density that were established under *Vacciniosa* and *Oxalidosa* site conditions, respectively. The differences in stem straightness among the trials of the same initial density that were established under various site conditions, were statistically non-significant.

Branch number in a whorl was influenced by both initial density and site conditions, the latter having larger impact than the initial density. There was no statistically significant influence of low and intermediate density on branch number in a whorl while less branch number in a whorl was noticed at the trials of high density. Statistically significant differences (P<0.05) in branch number in a whorl were found when comparing the trials of 15,000, 13,300 and 8,000 trees/ha density that were established under *Vacciniosa*, *Vaccinio-myrtillosa* and *Oxalidosa* site conditions, respectively with at the trials with lower density of trees. Nylinder (1959), Moltensen et al. (1985) and Handler and Jakobsen (1986) had also indicated that there was limited or no influence of density on branch number in a whorl. After Nylinder (1959), branch number in a whorl was influenced by genetic factors and the impact of environment had no considerable effect. Jokinen and Kellonjaki (1982) had determined a decrease in branch number in a whorl as well as decrease of the total branch number when the initial Scots pine density is high. Johansson (1992) found a relationship of 10 mm and thicker branch number in a whorl in the Norway spruce of low initial density (1,600 - 4,444 trees/ha). Branch diameter as well as the diameter of the thickest branches diminished at increased density or decreased site fertility. When the initial density augmented from 3,000 trees/ha to 8,000 trees/ha, the mean branch diameter decreased 1.0 mm and 3.0 mm at the trial that was established under *Vacciniosa* and *Oxalidosa* site conditions, respectively. The diameter of the thickest branches decreased 1.5 mm and 3.2 mm, respectively. The corresponding influence of trial density on branch thickness was found by Moltesen et al. (1985), Schmaltz (1991), Spellmaun and Nagel (1992) and others. By comparing the trials of the same initial density that were established under *Vacciniosa* and *Oxalidosa* site conditions, it was found that the mean branch diameter and the diameter of the thickest branches under first site conditions were lower in 0.3 - 2.4 mm and 2.0 - 5.0 mm, respectively. The differences in diameter of the thickest branches were statistically significant when comparing the trials of the same density that were established under *Vacciniosa* and *Oxalidosa* site conditions. Branches were thicker at the trials established under more fertile site conditions (Uusvara, 1975), despite their dieback starts earlier at the trials of the same density (Lamsa et al., 1990).

The thickest trees had the highest mean branch diameter and the highest mean diameter of the thickest branches as well. Moreover, the diameter of the thickest branches tended to enlarge more rapidly than the mean branch diameter when the tree diameter increased. It agrees well with the previously published results (Uusvara, 1975; Kellomaki and Vaisanen, 1986; others).

Basic wood density and late-/early-wood ratio were not affected by the initial density of trees, however, it was influenced by site conditions and tree position in the stand. Pines growing under *Vaccinio-myrtillosa*, *Oxalidosa* and *Vacciniosa* site conditions had the highest, slightly lower and the lowest basic wood density, respectively. Also, the lowest basic wood density was observed for the trees of worst growth while the trees of 1.1 - 1.4 relative diameter had the highest basic wood density. Maeglin (1967) had found that initial stand density had no statistically significant influence on basic wood density for *Pinus banksiana* Lamb. and *Pinus resinosa* Ait. The same results for *Pinus sylvestris* L. were reported by Martynov (1978).

Absence of strong relationship between the initial density and basic wood density implies that management of wood quality might be based on tree morphological traits, stand stability and productivity. If wood quality were defined by stem straightness, branch thickness in a tree height between 1 and 2 metres and branch number in a whorl, it would imply that a decrease in growth space might increase wood quality. Thus, the strategy of growing high-quality-timber is high initial stand density and suppression of individual growth at young age. However, strong suppression of individual growth at young age reduces stand stability when the stand becomes sensitive to diseases, climatic factors and intensive self-thinning starts. Therefore, utilisation of suppression of individual growth at young age is limited. Among-individual variation in stem straightness, branch thickness and number in a whorl and basic wood density is rather high, therefore, for a seek of improved wood quality, tree selection in the stand ought to be performed by quality traits. The seedlings having desirable genetic features should be used for reforestation purposes too. For a seek of growing up the timber of equal quality, the initial stand density on poor sites might be lower. Productive and sustainable Scots pine stands are ensured when planting 3 - 8 thou. seedlings/ha. Exact initial stand density within these limits should be chosen according to the wood quality desired, site conditions, seedling genetic value and survival.

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ВЛИЯНИЕ НАЧАЛЬНОЙ ГУСТОТЫ НА РОСТ И КАЧЕСТВО ДРЕВЕСИНЫ КУЛЬТУР СОСНЫ В ЗАВИСИМОСТИ ОТ УСЛОВИЙ МЕСТОПРОИЗРАСТАНИЯ

А. Малинаускас

Резюме

Изучены культуры сосны различной густоты посажены в брусничных, бруснично-черничных и кисличных типах леса.

Начальная густота культур влияла на прямолинейность стволов, толщине сучьев и их количестве в мутовке, устойчивости культур к грибным заболеваниям и неблагоприятным климатическим факторам, однако не имело влияние на плотность и соотношение поздней и ранней древесины. Культуры растущие на более плодородных почвах характеризуются менее прямолинейными стволами, более толстыми сучьями и большим количеством их в мутовке. Плотность и соотношение поздней и ранней древесины от начальной густоты культур не зависит, но зависит от плодородия почвы и социального положения деревьев в древостое. Наименьшая плотность древесины в росте отставших деревьев, а наибольшая – деревьев 1,1-1,4 относительного диаметра,

Выращивание продуктивных и стабильных сосновых насаждений обеспечивает начальная густота от 3 до 8 тыс.шт. га$^{-1}$. Конкретную начальную густоту в упомянутых пределах предопределяет желамое качество древесины и экономические условия. Изменчивость прямолинейности стволов, толщины сучьев и плотности древесины между индивидами высокая, поэтому в целях улучшения качества древесины нужно использовать отбор деревьев в древостое по признакам качества, а также при закладке лесных культур надо использовать посадочный материал с соответствующими генетическими свойствами.

Ключевые слова: культуры сосны, начальная густота, рост, качество древесины.