# Influence of Initial Density and Planting Design on the Quality of Butt Logs in Scots Pine (*Pinus sylvestris* L.) Plantations

ANTANAS MALINAUSKAS
*Lithuanian Forest Research Institute, LT-4312 Girionys, Kaunas distr., Lithuania*

**Malinauskas A.** 2003. Influence of Initial Density and Planting Design on the Quality of Butt Logs in Scots Pine (*Pinus sylvestris* L.) Plantations. *Baltic Forestry*, 9 (2): 10–15.

Studies of different initial density and planting design were carried out in 20 and 25-year-old pine plantations. The initial density of square planting design varied from 500 to 25,000 trees/ha while stands of rectangular planting design were established according to the following schemes: 5.00x2.00; 5.00x1.00; 4.00x0.50; 2.00x1.00; 3.00x0.75; 3.00x1.20 and 1.0x0.5 m.

Initial stand density had an effect on the survival, tree diameter, stem volume, thickness of branches and straightness of butt logs. In stands of rectangular planting design the mean diameter of all and the thickest branches is less than that in stands of square planting design. With increasing tree diameter the mean diameter of the thickest branches in stands of rectangular planting design increase less than in these of square design. With increasing rectangularity of planting design, differences in the diameter of the thickest branches between the stands of rectangular and square planting design increase as well. In stands of rectangular planting design branches growing in the direction of rows are insignificantly thinner than these directed towards the spaces between rows. Planting design has a very insignificant influence on stem ovality only under rectangularity 1:4 or more. Under rectangularity 1:2.5 - 1:5 the crookedness of butt logs in stands of rectangular planting design is less than in stands of square planting design.

**Key words:** Scots pine, initial density, planting design, quality of butt logs

## Introduction

Taking into account site conditions, the chosen species composition and initial density actually predetermine the stability and productivity of future stands, timber quality, planting and growing costs as well as the profitability of stands. The productivity and wood quality of stands cannot be the same, if the spacing of trees in an area is of regular or highly irregular pattern (Pisarenko, Merzlenko 1979). Therefore, initial spacing of stands can be ascertained only by taking into account the planting design of trees. The authors wanted to stress that initial density of stands as an index of their quality fails to be an "informing" value and suggested to supplement it with the rectangularity index. It is defined as the ratio of distances within rows and row-to-row distances.

While establishing plantations it is possible to regulate not only the initial density, but also the form of growing space. For a long time most often it was suggested to use square or similar to it planting design, because it was thought that rectangular planting design leads to lower stand productivity due to an earlier starting competition between trees within rows and because the growing space would not be used effieciently (Salminen&Varmola 1993). In the direction of free space stems and crowns become asymmetrical, while branches become thicker. Studies carried out (Dippel 1982; Handler&Jakobsen 1986; Daniels&Schultz 1975, Kramer 1980, Thren 1984, Nemisto 1995 et al.) failed to ascertain these effects, or the influence of rectangular spacing was insignificant. On the contrary, Shinkarenko et al. (1976) who had studied the effect of various spacings on the growth of stands recommended to establish plantations with 2.5-3.0 x 1,0 m distances. Evaluating the growth of spruce stands, the best planting design parameters as well as initial density are 3.2-4.8 x 0.6 m (Merzlenko, Koturanov 1991). The most favourable planting design, taking into consideration increment and diameter, stem form and total costs, is 2.4x0.4 m (Thren 1984). Kramer (1980) had generalized the studies of coniferous stands in Germany and Austria and drew a conclusion that rectangular planting design is better while establishing plantations than square planting design.

The aim of these studies is to evaluate the influence of planting design on the growth of pine stands, thickness of branches, straightness and quality of butt logs.

## Materials and methods

The studied 25-year-old pine stands of various initial density and planting design were established on an entirely prepared soil of clear-cut pine stand under *Vacciniosum* site conditions. The planting was designed as follows: 4.47x4.47; 2.24x2.24; 1.82x1.82; 1.50x1.50; 1.22x1.22; 1.12x1.12; 0.82x0.82; 0.63x0.63; 5.00x2.00; 5.00x1.00; 3.00x1.20; 3.00x0.75; 2.00x1.00; 1.00x0.50 m. Each area comprised only one block without replications. The area of each planting design variant was 0,10 ha. In these stands the diameter of all trees and the height of 1-4 trees as well as the height to the first live branch for every thickness degree were measured. In each planting design variant the diameter at breast (1,3 m) and 3,5 m height of 50 randomly selected trees was measured along rows and perpendicular to them, the thickness of branches at 1,5 and 3,5 m height by distributing them into growing in the direction of rows and perpendicular to it was measured according to (Salminen and Varmola 1993) methodics. The diameter of branches was measured at 3 cm distance from the stem perpendicular to the branch axis, seeking to eliminate the collar of branches (Persson 1977). For 75 randomly selected trees stem crookedness was measured on a 5 m long stem segment from the ground surface. Evaluating the crookedness of a 5 m long stem segment, the greatest perpendicular between the stem and the ends of a straight line excluding root collar was measured.

In pine plantations established on abandoned agricultural land with 2.0x0.5 m spacing at the age of 12 years every other tree in a row or every other row were removed. Thus, owing to cuttings, 2.0x1.0 and 4.0x0.5 m spacings were formed with 2 replications. After felling, mean height of the plantations with 2.0x1,0 spacing was 4.5 m, while in those with 4.0x0.5 – 4.4 m. Live branches were found almost close to the ground surface. After 8 years (at the age of 20 yr.) the diameter of all trees and the height of 1-4 trees for each thickness degree were measured. In each variant the thickness of branches in whorls at 1.5-2.0 m height on 75 randomly selected trees was measured.

Descriptive statistics of the main traits of experimental plantations are presented in the table.

## Results

The survival of stands at the age of 25 years varied from 91 to 18% and depended on the initial density (Table 1).

With increasing initial density the survival of plantations decreases. Rectangularity in plantations with up to 3, 000 trees/ha at initial density had no influence on the survival, while in plantations of higher initial density and rectangular planting design it was greater as compared to square planting design plantations. The survival of square spacing plantations with initial density 4, 444 trees/ha is 51, that of rectangular spacing plantations is 61%, in square planting design with initial density 15, 000 trees/ha – 29%, 25, 000 trees/ha – 18%, while in plantations of rectangular planting design with initial density 20, 000 trees/ha – 28%.

**Table 1.** Dendrometric characteristics of pine plantations of various planting design

| Planting design, m | Number of survived trees, trees $ha^{-1}$ | Mean height, m | Height to live branches, m | DBH, cm | Volume, $m^3ha^1$ |
|---|---|---|---|---|---|
| *Vacciniosa* site conditions. 25-year-old stand | | | | | |
| 4.47x4.47 | 456 | 9.9±0.4 | 1.6±0.1 | 16.8±0.5 | 58 |
| 2.24x2.24 | 1255 | 9.3±0.5 | 2.9±0.2 | 12.4±0.3 | 84 |
| 1.82x1.82 | 1897 | 10.1±0.4 | 4.4±0.2 | 10.6±0.2 | 104 |
| 1.50x1.50 | 2280 | 10.4±0.3 | 5.4±0.2 | 10.4±0.2 | 128 |
| 1.22x1.22 | 2904 | 10.4±0.4 | 4.8±0.2 | 10.0±0.2 | 127 |
| 1.12x1.12 | 3113 | 9.4±0.4 | 4.9±0.2 | 8.9±0.3 | 130 |
| 0.82x0.82 | 4291 | 9.2±0.4 | 4.7±0.2 | 8.0±0.1 | 137 |
| 0.63x0.63 | 4571 | 9.1±0.4 | 4.8±0.2 | 6.8±0.1 | 106 |
| 5.00x2.00 | 755 | 9.8±0.4 | 2.6±0.2 | 14.0±0.4 | 67 |
| 5.00x1.00 | 870 | 10.5±0.2 | 3.5±0.2 | 13.3±0.5 | 75 |
| 3.00x1.20 | 1763 | 10.3±0.3 | 4.2±0.1 | 11.3±0.4 | 113 |
| 3.00x0.75 | 2728 | 10.7±0.4 | 5.3±0.2 | 9.8±0.2 | 145 |
| 2.00x1.00 | 2459 | 10.5±0.4 | 4.2±0.2 | 10.1±0.2 | 129 |
| 1.00x0.50 | 5694 | 8.7±0.4 | 6.9±0.1 | 4.8±0.2 | 142 |
| *Vaccinio-myrtillosa* site conditions. 20-year-old stand. | | | | | |
| 2.00x1.00 | 367 | 9.0±0.2 | 3.2±0.1 | 11.0±0.1 | 115 |
| 4.00x0.50 | 337 | 9.0±0.2 | 3.3±0.1 | 11.4±0.1 | 116 |

Initial density had a distinct influence on the mean stem diameter. With increasing initial density the mean stem diameter decreases. The mean stem diameter in stands with up to 3, 000 trees/ha at initial density and rectangular planting design is higher than in stands of square planting design. The mean tree height under increasing initial density up to 4, 444 trees/ha increases, while exceeding 6, 667 trees/ha it starts diminishing. In stands of rectangular planting design, as compared to the stands of square planting design, the mean height is also greater, though statistically significant ($P \leq 0.05$) only in plantations with 2,000 trees/ha at initial density. Height from the ground surface up to the first live branch with increasing initial density rises at the beginning, but later it becomes constant. The greatest height of 5.4 m up to the first live branch is in stands with 4, 444 trees/ha at initial density. Spacing apparently has no influence on the height to the first live branch. With increasing initial density up to 4, 444 trees/ha the volume of stems increases, under 6, 667-15, 000 trees/ha it remains similar, while under 25, 000 trees/ha it becomes lower. A tendency has been observed that the stem volume is higher in stands of rectangular than in square planting design.

With increasing initial density the diameter of branches decreases, while with increasing height of branches from the ground surface their diameter increases (Table 2). In stands of rectangular planting design with the same initial density, as compared to square planting design, the diameter of branches is less. The dependance of branch thickness on the rectangularity of planting design has been ascertained (Table 3 ). Under rectangularity 1:2 the mean thickness of branches as compared to stands of square planting design comprises 92%, under rectangularity 1:2.5 – 89%, 1:4 – 85% and 1:5 – 84%. The mean diameter of the thickest branches under rectangularity 1:2 comprises 92%, under rectangularity 1:4 – 83% and 1:5 – 92%. In stands established on *Vaccinio-myrtillosum* sites the mean thickness of branches under rectangularity 1:2 is 10.5 mm, the mean thickness of the thickest branches – 18.2 mm, while under rectangularity 1:8, 10.8 and 19.9 mm, respectively.

**Table 2.** Diameter of all and the thickest branches at 1.5 and 3.5 m height from the ground surface in pine stands of square and rectangular planting design

| Planting design. m | Mean diameter of branches at 1.5 m height. mm | | Mean diameter of branches at 3.5 m height. mm | |
|---|---|---|---|---|
| | all | thickest | all | thickest |
| 4.47x4.47 | 20.7±1.8 | 39.0±1.9 | 29.8±2.8 | 45.2±2.9 |
| 2.24x2.24 | 16.3±1.3 | 28.0±1.3 | 20.1±1.1 | 32.4±1.5 |
| 1.82x1.82 | 13.4±0.9 | 21.8±1.1 | 17.8±0.9 | 25.5±1.5 |
| 1.50x1.50 | 12.6±0.9 | 22.8±0.7 | 17.5±0.9 | 25.2±1.0 |
| 1.22x1.22 | 12.6±0.9 | 21.8±0.9 | 14.5±0.8 | 21.3±1.1 |
| 1.12x1.12 | 12.5±0.8 | 20.3±0.9 | 14.4±0.7 | 21.0±1.0 |
| 0.82x0.82 | 11.0±0.7 | 17.4±0.6 | 12.9±0.6 | 17.3±0.8 |
| 0.63x0.63 | 9.6±0.7 | 14.7±0.7 | 11.2±0.7 | 16.2±0.7 |
| 5.00x2.00 | 17.1±1.4 | 31.4±1.4 | 26.8±1.7 | 37.5±1.9 |
| 5.00x1.00 | 13.6±1.0 | 25.7±1.4 | 17.9±1.2 | 25.4±1.6 |
| 3.00x1.20 | 12.8±0.9 | 21.7±0.9 | 16.0±0.5 | 22.9±1.5 |
| 3.00x0.75 | 10.9±0.8 | 18.7±0.7 | 15.2±0.4 | 22.5±0.8 |
| 2.00x1.00 | 11.8±0.8 | 20.7±0.9 | 4.9±0.8 | 22.4±1.0 |
| 1.00x0.50 | 8.9±0.6 | 14.6±0.6 | 10.8±0.6 | 17.1±0.8 |
| 2.00x1.00 | 10.5±0.3 | 18.2±0.8 | | |
| 4.00x0.50 | 10.8±0.3 | 19.9±0.9 | | |

**Table 3.** Dependance of the thickness of branches at 1.5 m height from the ground surface on the rectangularity of planting design

| Planting design. m | Thickness of branches. % | |
|---|---|---|
| | all | thickest |
| square 1:1.0 | 100 | 100 |
| rectangle 1:2.0 | 92 | 92 |
| rectangle 1:2.5 | 89 | 91 |
| rectangle 1:4.0 | 85 | 83 |
| rectangle 1:5.0 | 84 | 92 |

With increasing tree diameter the mean thickness of the thickest branches (Fig. 1) increases. With increasing tree diameter the mean diameter of the thickest branches in stands of rectangular planting design increases slower than in stands of square planting design.

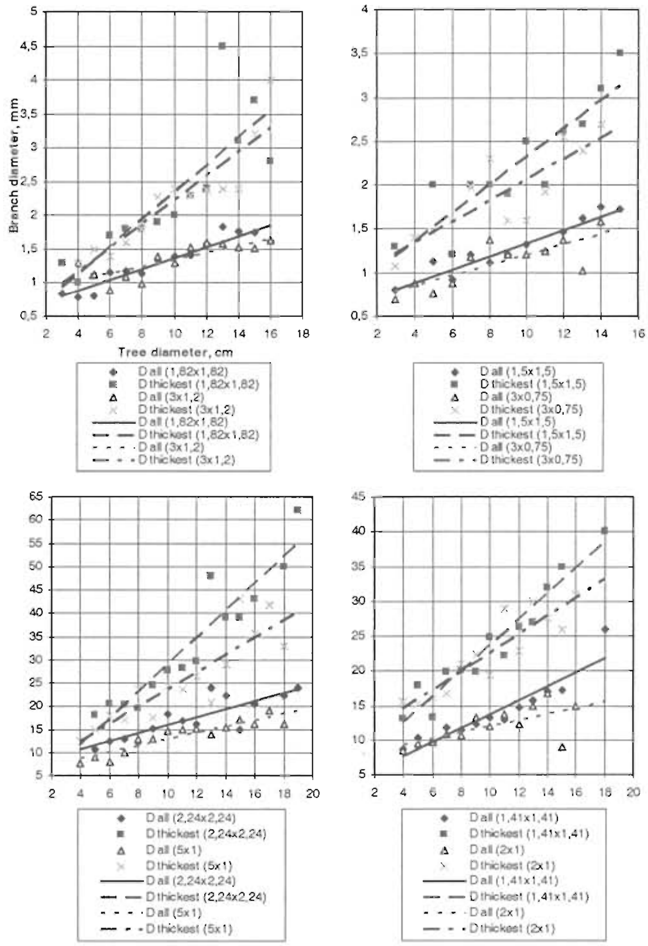


**Figure 1.** Dependance of branch diameter on tree diameter in stands of square and rectangular planting design

Planting design had an insignificant effect on the thickness of branches depending on their direction towards the rows (Table 4). The diameter of branches directed towards the lines of rows in rectangular planting design stands was insignificantly less than that of branches directed towards spaces between rows. The differences are slightly more significant comparing the diameters of the thickest branches and the diameters of all branches. Only under rectangularity 1:4 and 1:5 an insignificant tapering of stems has been ascertained.

With increasing initial density the crookedness of butt logs decreases (Table 5). In stands of rectangular planting design of the same initial density, as compared to stands of square planting design, the crook-

**Table 4.** Diameter ratios of trees and branches measured in the direction of rows and perpendicular to them

| Planting design, m | Ratio of tree diameters | Ratio of the diameters of branches | |
|---|---|---|---|
| | | all | thickest |
| square 1:1.0 | 1.00 | 1.00 | 1.00 |
| rectangle 1:2.0 | 1.00 | 1.01 | 1.07 |
| rectangle 1:2.5 | 1.00 | 1.08 | 1.14 |
| rectangle 1:4.0 | 1.01 | 1.09 | 1.09 |
| rectangle 1:5.0 | 1.02 | 1.04 | 1.04 |

**Table 5.** Crookedness of butt logs in stands of square and rectangular planting design

| Planting design, m | Crookedness, cm m[1] | |
|---|---|---|
| | all trees | potential crop trees |
| 4.47x4.47 | 1.37±0.09 | 1.08±0.05 |
| 2.24x2.24 | 1.29±0.08 | 1.00±0.05 |
| 1.82x1.82 | 0.88±0.04 | 0.81±0.04 |
| 1.50x1.50 | 0.81±0.07 | 0.60±0.03 |
| 1.22x1.22 | 0.73±0.03 | 0.50±0.03 |
| 1.12x1.12 | 0.70±0.03 | 0.56±0.03 |
| 5.00x2.00 | 1.27±0.08 | 1.02±0.05 |
| 5.00x1.00 | 0.97*±0.07 | 0.82*±0.04 |
| 3.00x1.20 | 0.69*±0.03 | 0.64*±0.03 |
| 3.00x0.75 | 0.66*±0.03 | 0.60±0.03 |
| 2.00x1.00 | 0.79±0.04 | 0.65±0.03 |

* Differences are statistically significant at P≤0.01 level as compared to stands of square planting design with the same initial density

edness of butt logs is less. The differences are statistically significant (P≤0,05) comparing stands of square and rectangular planting design under rectangularity 1:2.5 – 1:5.

The mean diameter of potential crop trees with increasing initial density up to 3, 000 trees/ha decreases, while in stands with 3, 000 trees/ha and at higher initial density it is similar (Table 6). In stands of rectangular and square planting design with the same initial density the mean diameter of potential crop trees is also alike.

With increasing initial density the quality of butt logs rises. If in stands with 500 trees/ha at initial density butt logs of A quality class comprise 13%, while in stands with 8, 000 trees/ha at initial density stands they make up 82%. In stands of rectangular planting design, as compared to stands of square planting design with the same initial density, the quality of butt logs is higher. For example, in stands with 1.82x1.82 m planting design A quality class of butt logs comprise 50, B-25, C-17 and D-8%, while in stands of 3.00x1.20 m planting design A quality class of butt logs makes up 68, B-18 and C-14%.

**Table 6.** Mean diameter of potential crop trees and distribution of butt logs by quality classes

| Planting design | Diameter of potential crop trees, cm | Distribution of butt logs by quality classes, % | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| 4.47x4.47 | 19.4 | 13 | 29 | 50 | 8 |
| 2.24x2.24 | 16.4 | 43 | 24 | 23 | 10 |
| 1.82x1.82 | 15.8 | 50 | 25 | 17 | 8 |
| 1.50x1.50 | 15.5 | 80 | 2 | 18 | |
| 1.22x1.22 | 15.0 | 82 | 18 | | |
| 1.12x1.12 | 15.2 | 98 | 2 | | |
| 5.00x2.00 | 18.2 | 34 | 31 | 26 | 9 |
| 5.00x1.00 | 17.1 | 48 | 27 | 19 | 6 |
| 3.00x1.20 | 16.0 | 68 | 18 | 14 | |
| 3.00x0.75 | 15.0 | 97 | 3 | | |
| 2.00x1.00 | 15.5 | 97 | 3 | | |

## Discussion

The influence of initial density on stand parameters, i.e. mean height, diameter, stem volume and height to live branches is widely described in the literature and the results obtained reveal the already known regularities. A tendency was observed that the volume of stems in stands of rectangular planting design is higher than that in stands of square planting design. Better growth of pine stands under rectangular than under square planting design when the row was 2.5 m, while the distances within rows were 0.4-4.0 m, has been ascertained by Shinkarenko et al (1976). The most favourable spacing of pine stands, taking into account stem diameter increment, stem form and growing costs is 2.4x2.4 m (Thren 1984).

Klaus (1987) admits that in establishing plantations optimal spacing of trees at their final development stage should be taken into consideration. The best planting design of spruce ensuring a triangular spacing structure in a mature stand is 2.6x1.5 m. Triangular spacing of trees may be considered to be as one variant of rectangular planting design. Evaluating the growth of spruce stands, the best width between rows is 3.2-4.8 m, while the initial density 5.2-3.5 thou. trees/ha (Merzlenko, Koturanov 1991). Melzer *et al.* (1992) and Salminen & Varmola (1993) who had studied the 17-year-old pine stands of rectangular and square planting design failed to ascertain somewhat more significant growth differences.

The dependance of the thickness of branches on initial density and their height from the ground surface is described in a series of publications (Persson 1977, Schmaltz 1991, Shtukin 1993 *et al.*). In general, the thickest (living) pine branch is found in the central portion of the stem. Uusvaara (1975) has found, that the thickest branch is 60% at relative stem height when the age of trees is over 50 yr. and up to 40% for trees younger than 30 yr. The thickness of branches increases with increasing height in the lower stem portion (Persson 1977) and decreases with increasing height in the upper stem portion (Lehtonen 1978). The thickness of branches increases with increasing tree diameter (Uusvaara 1975; Vaisanen 1986).

The mean thickness of all branches and the thickest ones in stands of rectangular planting design is less than in stands of square planting design. An analogous tendency has been ascertained by Salminen and Varmola (1993). The mean thickness of branches with increasing rectangularity up to 1:5, while the diameter of the thickest branches with increasing rectangularity up to 1:4, decrease. Under rectangularity 1:8 the diameter of branches, especially that of the thickest ones, is greater than under rectangularity 1:2. Obviously, with increasing rectangularity and (or) row-to-row distances, the diameter of branches, perhaps the diameter of the thickest branches, initially decreases, while later on with increasing above mentioned parameters it starts augmenting as well.

Especially important is the fact that with increasing tree diameter the mean diameter of the thickest branches in stands of rectangular planting design increase less than in stands of square planting design. Besides, with increasing rectangularity the differences in diameters of the thickest branches between stands of rectangular and square planting design increase as well.

In stands of rectangular spacing branches growing in the direction of rows are insignificantly thinner than those directed towards spaces between rows. This has a slightly greater influence on the diameter of the thickest branches than on the mean diameter. Analogous data were obtained by Salminen and Varmola (1993). Planting design has a very insignificant influence on stem ovality only under rectangularity 1:4 or more. This corresponds to the conclusion of Daniels and Shultz (1975), that prevailing winds have greater influence on stem ovality than planting design.

The crookedness of butt logs decreases with increasing initial density. It complies with the results obtained by Huuri&Lahde (1985), Agestam et al (1998), and Prescher&Stahl (1986). Under rectangularity 1:2.5 – 1:5 the crookedness of butt logs in stands of rectangular planting design is less than in stands of square planting design. Thren (1984) studied pine stands of rectangular spacing and found out that 2.4x0.4 m is the most favourable planting design taking into account tree increment and diameter, stem form and total costs. Technical quality of pine stems is independent of planting design (Salminen&Varmola 1993).

Thinner branches and straighter stems preconditioned higher technical quality of stems in stands of rectangular planting design as compared to stands of square planting design with the same initial density. In stands of square planting design with initial density of three thousand seedlings it is already possible to select all potential crop trees the butt logs of which meet A quality class requirements. Rectangular planting design allows to reduce initial density by about 500 trees/ha maintaining the same quality class of butt logs of potential crop trees as in stands of square planting design with by 500 trees/ha greater initial density.

## Conclusions

1. The mean diameter of all branches and the thickest ones in stands of rectangular planting design is less than in square design stands. The mean diameter of branches with increasing rectangularity up to 1:5, and the diameter of the thickest branches with increasing rectangularity up to 1:4, decrease.

2. With increasing tree diameter the mean diameter of the thickest branches in stands of rectangular planting design increases less than in stands of square planting design. With increasing rectangularity of planting design the differences in diameter of the thickest branches between stands of rectangular and square planting design increase as well.

3. In stands of rectangular planting design the branches growing in the direction of rows are insignificantly thinner than these directed towards the spaces between rows. Planting design has a very insignificant influence on stem ovality only under rectangularity 1:4 or more.

4. With increasing initial density the crookedness of butt logs decreases. Under rectangularity 1:2.5-1:5 the crookedness of butt logs in stands of rectangular planting design is less than in stands of square planting design.

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Received 08 May 2003

## ВЛИЯНИЕ НАЧАЛЬНОЙ ГУСТОТЫ И СХЕМЫ ПОСАДКИ НА КАЧЕСТВО ПЕРВИЧНЫХ БРЕВЕН СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.)

**А. Малинаускас**

*Резюме*

Исследования проведены в 25-летних культурах сосны различной густоты и различной схемы размещения посадочных мест. Начальная густота культур с квадратным размещением посадочных мест варировала от 500 до 25000 шт.га$^{-1}$. а культуры с прямоугольным размещением посадочных мест были созданы по следующим схемам посадки :5.00 x2.00. 5.00 x 1.00. 4.00 x 0.50. 2.00 x 1.00. 3.00 x 0.75. 3.00 x 1.20 и 1.00 x 0.50 м.

Начальная густота культур влияла на сохранность культур. толщину деревьев. запас. толщину ветвей и кривизну первичных бревен.

В культурах с прямоугольным размещением посадочных мест средний диаметр всех и наиболее толстых ветвей был меньше чем в культурах с квадратным размещением посадочных мест. При увеличении диаметра деревьев средний диаметр наиболее толстых ветвей в культурах с прямоугольным размещением посадочных мест увеличивается меньше. по срвнению с культурами с квадратным размещением. При увеличении прямоугольности размещения разница между диаметрами ветвей наиболее толстых деревьев в культурах с квадратным и прямоугольным размещением также увеличивается. В культурах с прямоугольным размещением посадочных мест ветвеи растущие вдоль рядов незначительно тоньше. по срвнению с ветвями растущими по направлению междурядии. Влияние размещения посадочных мест на овальность стволов крайне незначительно и проявляется только в культурах при прямоугольности 1:4 и больше. При прямоугольности размещения посадочных мест 1:2.5 – 1:5 кривизна первичных бревен в культурах с прямоугольным размещением посадочных мест меньше по сравнению с культурами с квадратным размещением.

**Ключевые слова:** сосна обыкновенная. начальная густота. размещение посадочных мест. качество первичных бревен.