# Economical Evaluation of the Scots Pine Plantations of Different Initial Density

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Scots pine plantations of various initial density that were established under *Vacciniosum* and *Oxalidosum* site conditions were studied. Wood quality was evaluated, growth forecast until the age of maturity was performed and econimcal efficiency of their growing computed. The initial density of the plantations established under *Vacciniosum* site conditions was 500, 2000, 3000, 4440, 5000, 6670, and 8000 trees ha$^{-1}$, age was 25 years. Under *Oxalidosum* site conditions, the initial density was 3330, 5000, 6670, and 8000 trees ha$^{-1}$ and age was 38 years. The economical efficiency of the planting density for Scots pine was examined at three levels of interest rate (0%, 2% and 3%). Under the conditions of interest rate reaching 2-3% and the stand productivity ranging from intermediate to the maximum, the initial density of Scots pine plantations on *Vacciniosum* sites ($H_{100} = 27$) and *Oxalidosum* sites ($H_{100} = 33$) should be within the range of 2-3 thousand trees ha$^{-1}$ and 3-5 thousand trees ha$^{-1}$, respectively.

Key words: Scots pine, initial density of plantations, economical evaluation

## Introduction

Currently, the Scots pine plantations, depending on site fertility, are established at the initial densities of 5 – 9 (11) thousand trees ha$^{-1}$. On less fertile sites, the initial density is increased. In different countries of Europe, the Scots pine plantations are established at different density. Recommendations on initial density of Scots pine plantations have been prepared by a number of authors from various countries and it varies from 1300 to 25000 trees ha$^{-1}$ (Dittmar 1975, Flöhr 1975, Thomasius 1975, Mráček 1983, Huuri & Lähde 1985, etc). The Scots pine plantations of the lowest density are established in the Scandinavian countries. For instance, according to the Forestry Act (1994), the initial density of Scots pine plantations in Sweden on the sites where tree height at the age of 100 years is 20 metres ($H_{100} = 20$) and 24 metres ($H_{100} = 24$), should be at least 1300 trees ha$^{-1}$ and 1600 trees ha$^{-1}$, respectively. In practice, the initial density of Scots pine plantations in Sweden is 2000-2500 trees ha$^{-1}$ (Freij & Tosterud 1989, Lohmander 1994). The Scots pine plantations of low initial density are established in Finland and in Norway as well (Uusvaara 1985, Strand et al. 1997).

The activities in optimising initial plantation density and simultaneously maximising obtained profit have indicated that the sparse plantations are superior to the dense ones (Türkevič et al. 1974, Valsta Lauri 1982, Lohmander 1994 ir kt.). In North Sweden on sites $H_{100} = 20$ and $H_{100} = 24$, the optimum initial density of Scots pine plantations is 670 and 945 trees ha$^{-1}$, respectively (Gong 1995, 1998). On the other hand, higher initial density ensures higher quality of wood (Persson 1976, 1977, Johansson 1992, Niemistö 1995, Björklund & Hörnfeldt 1996 ir kt.). There is always higher demand for the wood of higher quality in the market which leads to the higher price. In 2000, the mean price for Scots pine logs of the I-st sort in Lithuania was higher by 47% than the price for the logs of the II-nd sort (MEC News 2001).

The aim of this study is evaluate the relationships between the initial density of plantations and wood quality and to compute economical efficiency of growing Scots pine plantations of various initial density established under *Vacciniosum* and *Oxalidosum* site conditions.

## Materials and methods

Scots pine plantations of various density were evaluated in Dubrava experimental forest enterprise. Age of the stand on *Vacciniosum* and *Oxalidosum* sites was 25 years and 38 years, respectively. The initial density of the plantations established under *Vacciniosum* site conditions was 500, 2000, 3000, 4440, 5000,

6670, and 8000 trees ha$^{-1}$. Under *Oxalidosum* site conditions, the initial density was 3330, 5000, 6670, and 8000 trees ha$^{-1}$.

The diameter of all trees and heights of 1-4 trees per each category of thickness were measured as well as the number of trees in 1 ha was recorded and other major dendrometric characters were evaluated. Within each category of the initial density, the diameter of the thickest branches between 0 and 5,5 m height, stem crookedness (cm m$^{-1}$), the number of branches having acute angle recalculated and stem diameter at the height of 5,5 metres was measured for 100 randomly selected trees. Based on these parameters, a quality class for the butt logs was determined.

A growth forecast for plantations of different densities (mean diameter, height, volume and harvested part of the stand during the thinnings) was performed according to the models of the dynamics of the major stand dendrometric characters (Kuliešis 1993) and programmes for thinnings (Juodvalkis et al. 1986). Besides, it was corrected following the results on productivity of Scots pine plantations of various density at the maturity age by Elfving (1981) and Agestam et al. (1998).

In Lithuania, mean site index of pine woods is II,3 and mean volume of the matured pine stands reaches 288 m$^3$ ha$^{-1}$ (Statistics of the Lithuanian forests, 1998). The maximum productivity of the matured Scots pine stands of the mentioned site index is 423 m$^3$ ha$^{-1}$ (Kuliešis 1993). Thus, the pine woods of Lithuania on average reach 68% of their potential productivity.

The technological cost of establishment of plantations was calculated by equation 1:

$$S = S \left[ (t_j * d_j) (1 + p_1) \right] * (1 + p_2) + S (m_{ij} * k_i) + S (n_{ei} * z_e), \quad (1)$$

S – cost of establishment of plantations;
j – works of establishment;
i – assortment of the materials used;
$t_j$ – expenditures of the working time to do job j;
$d_j$ – cost of time unit (hour) to do job j, Lt;
$p_1$ – additional salary (holidays, etc. 12%);
$p_2$ – social insurance of the employees (30%);
$m_{ij}$ – expenditures of material i to do job j;
$k_i$ – market price of unit of the material i;
$n_{ej}$ – time expenditures of mechanism e to do job j(hours);
$z_e$ – cost of 1 hour work exploitation of mechanism e.

Expenditures of working time of the mechanism or human for forest regeneration purposes were calculated according to the time standards used at the forest enterprises and based on the practical experience while running these works.

The cost of 1-hour-exploitation of mechanisms or other long-term-use agricultural implements were computed by using equation 2:

$$Z_e = ( V_e - V_1 ) / E + R / E + S (D_{ed} * k_d) + I, \quad (2)$$

$Z_e$ - cost of 1-hour-exploitation of mechanism e;
$V_e$ – purchase price of mechanism e;
$V_1$ – scrap value of the mechanizm, up to 10% of the initial value;
E – foreseen period of exploitation of the mechanism which is determined by the normatives of use of the long-term property that had been approved by the Government of the Republic of Lithuania;
R – exploitation cost for the current maintenance and repair that are determined in % of the initial price for the entire exploitation period;
$D_{ed}$ – expenditure for fuel and lubricants d for mechanism e per working hour;
$k_d$ – price for unit of d fuel and lubricants, Lt;
I – various other expenses (exploitation of garages or parking areas, delivery of materials, small stock, etc.), 10% of the exploitation (maintenance, fuel and lubricants) expenses.

The economical effect of growing up of stands was calculated by using equation 3:

$$E = [\sum P_j (1+R)^{-n} - \sum S_j / (1+R)^{-n}] / a \quad (3)$$

E – annual economical effect, Lt ha$^{-1}$;
$P_j$ – income from the thinning of 1 ha mature stand of density j;
$S_j$ – cost of establishment and care until the age of maturity of 1 ha stand of density j;
R – interest rate;
n– period (years) from making expenditures until harvesting of the stand;
a – rotation age.

## Results

It was found that in the unthinned 25-year-old Scots pine plantations of higher initial density, the mean stem diameter decreased while the height initially increased but later decreased too. The volume also increased until plantation density reached 4440 trees ha$^{-1}$ while at higher densities it remained stable (Table 1). In older (38 years old) Scots pine plantations, mean diamater, height and volume are similar in all combinations of the initial density.

A foreseen dendrometric characteristics of the plantations at the age of 100 years is given in Table 2. The foreseen mean diameters, heights and volumes of the

**Table 1.** Dendrometric characteristics of the plantations

| Initial plantation density, trees ha⁻¹ | The number of trees ha⁻¹ | Mean diameter, cm | Mean height, m | Stem volume, m³ ha⁻¹ |
|---|---|---|---|---|
| Pinetum vacciniosum stand. Age 25 years. | | | | |
| 500 | 456 | 16.8 | 9.9 | 58 |
| 2000 | 1255 | 12.4 | 9.3 | 84 |
| 3000 | 1897 | 10.6 | 10.1 | 104 |
| 4440 | 2280 | 10.4 | 10.4 | 128 |
| 5000 | 2459 | 10.1 | 10.5 | 129 |
| 6670 | 2904 | 9.2 | 10.4 | 127 |
| 8000 | 3113 | 8.9 | 9.4 | 130 |
| Pinetum oxalidosum stand. Age 38 years. | | | | |
| 3330 | 1432 | 18.1 | 18.5 | 380 |
| 5000 | 1743 | 16.8 | 18.6 | 380 |
| 6670 | 1785 | 16.4 | 17.8 | 364 |
| 8000 | 1840 | 16.7 | 18.6 | 402 |

**Table 2.** Forecasted dendrometric characteristics of the plantations at the age of 100 years

| Initial plantation density, trees ha⁻¹ | Mean diameter, cm | Mean height, m | Stem volume, m³ ha⁻¹ | Harvested part of the stand during the thinnings, m³ ha⁻¹ |
|---|---|---|---|---|
| *Pinetum vacciniosum stand* | | | | |
| 500 | 37.5 | 26.0 | 370 | 75 |
| 2000 | 30.0 | 26.0 | 430 | 189 |
| 3000 | 30.0 | 26.0 | 460 | 251 |
| 4440 | 31.0 | 26.0 | 470 | 269 |
| 5000 | 32.0 | 26.0 | 480 | 274 |
| 6670 | 32.0 | 27.0 | 490 | 278 |
| 8000 | 32.6 | 27.0 | 490 | 281 |
| *Pinetum oxalidosum* stand | | | | |
| 3330 | 37.0 | 33.0 | 570 | 326 |
| 5000 | 39.0 | 34.0 | 590 | 359 |
| 6670 | 40.0 | 34.0 | 600 | 366 |
| 8000 | 41.0 | 34.00 | 610 | 370 |

**Table 3.** Distribution of but logs by the quality classes, %

| Initial plantation density, trees ha⁻¹ | Quality classes | | |
|---|---|---|---|
| | I | II | III |
| *Pinetum vacciniosum* stand | | | |
| 500 | 3.8 | 77.5 | 17.7 |
| 2000 | 13.5 | 77.1 | 9.4 |
| 3000 | 28.2 | 71.8 | 0 |
| 4440 | 40.9 | 59.1 | 0 |
| 5000 | 48.6 | 51.4 | 0 |
| 6670 | 77.6 | 22.4 | 0 |
| 8000 | 100 | 0 | 0 |
| *Pinetum oxalidosum* stand | | | |
| 3330 | 12.5 | 80.5 | 7.0 |
| 5000 | 38.4 | 61.6 | 0 |
| 6670 | 54.3 | 45.7 | 0 |
| 8000 | 64.0 | 36.0 | 0 |

and III-rd categories made up 3.8%, 77.5%, and 17.7%, respectively. The initial density of 8000 trees ha⁻¹ created good conditions to cultivate the butt logs of the I-st category only if the trees to be harvested during the thinnings were selected skilfully.

In comparison to *Vacciniosum* site, the quality of the butt logs in the stands established under *Oxalidosum* site was lower. For instance, in the plantations at the initial density of 5000 trees ha⁻¹ on *Vacciniosum* site the butt logs of the I-st catgegory made up 48.6% and at the initial density of 8000 trees ha⁻¹ even 100%. Under *Oxalidosum* site in the plantations of the same densities the butt logs of the I-st category comprised 38.4% and 64.0%, respectively (Table 3).

Cost of growing up of plantations are made of the cost for their establishment, tending, thinnings, forest fire protection, amelioration net, etc. With increased intial density, the expenses for establishment and protection of plantation increase as well (Table 4). The

**Table 4.** Cost of establishment and care of the plantations, Lt ha⁻¹

| Initial plantation density, tree ha⁻¹ | Soil preparation | Planting and additional planting | Plantation care and protection | Totally |
|---|---|---|---|---|
| *Pinetum vacciniosum* stands | | | | |
| 500 | 166 | 98 | 281 | 545 |
| 2000 | 248 | 390 | 520 | 1158 |
| 3000 | 372 | 586 | 687 | 1645 |
| 4440 | 372 | 867 | 920 | 2159 |
| 5000 | 372 | 976 | 1111 | 2459 |
| 6670 | 496 | 1302 | 1282 | 3080 |
| 8000 | 496 | 1562 | 1498 | 3556 |
| *Pinetum oxalidosum* stands | | | | |
| 3330 | 372 | 650 | 981 | 2003 |
| 5000 | 372 | 976 | 1271 | 2619 |
| 6670 | 496 | 1302 | 1562 | 3360 |
| 8000 | 496 | 1562 | 1794 | 3852 |

stands well reflect the influence of the plantation initial density, i.e.The possibilities to select the individuals of more rapid growth. Moreover, when forecasting dendrometric characters at the age of 100 years,the influence of fluctuations in soil fertility among different densities is eliminated.

The influence of the initial density of the plantations on the quality of but logs was evident (Table 3). In the plantations with the initial density of 500 trees ha⁻¹, which had been established under *Vacciniosum* site conditions, the butt logs of the I-st, II-nd,

expenses for establishment and care of the plantation with the density of 3000 trees ha^{-1} are 2.2 times lower when comparing with the plantation the density of which is 8000 trees ha^{-1}. Under *Vacciniosum* site conditions, the expenses of establishment and care of the plantations are lower than those under *Oxalidosum* site conditions.

The economical gain of growing up Scots pine plantations of various densities was calculated under the interest rate of 0%, 2% and 3% (Table 5). Moreover, the calculations were done under the assumption of maximum productivity of Scots pine plantations or close to that and of mean productivity of Scots pine stands in Lithuania. Under the 2% interest rate and

**Table 5.** Economical effect of growing Scots pine plantations of various densities (Lt ha^{-1}) at different interest rates

| Plantation initial density, trees ha^{-1} | The maximum plantation productivity or close to that | | | The mean plantation productivity | | |
|---|---|---|---|---|---|---|
| | Interest rate | | | | | |
| | 0 | 2 | 3 | 0 | 2 | 3 |
| *Pinetum vacciniosum* stand | | | | | | |
| 500 | 420 | 380 | 288 | 278 | 228 | 128 |
| 2000 | 566 | 564 | 471 | 376 | 340 | 215 |
| 3000 | 616 | 591 | 447 | 408 | 346 | 169 |
| 4440 | 632 | 575 | 370 | 417 | 324 | 85 |
| 5000 | 641 | 565 | 324 | 422 | 310 | 35 |
| 6670 | 682 | 558 | 252 | 448 | 297 | -49 |
| 8000 | 775 | 573 | 221 | 512 | 300 | -114 |
| *Pinetum oxalidosum* stand | | | | | | |
| 3330 | 730 | 706 | 541 | 485 | 416 | 211 |
| 5000 | 819 | 757 | 521 | 543 | 437 | 157 |
| 6670 | 856 | 753 | 432 | 566 | 416 | 54 |
| 8000 | 866 | 720 | 317 | 570 | 378 | -67 |

the maximum productivity of the plantations, optimum initial density of the plantations under *Vacciniosum* and *Oxalidosum* site conditions is 3000 trees ha^{-1} and 5000 trees ha^{-1}, respectively. Under the assumption that the plantation productivity will reach the mean value of Lithuanian pine woods only, optimum initial density under *Vacciniosum* and *Oxalidosum* site conditions would be 2000 trees ha^{-1} and 5000 trees ha^{-1}. Under the assumptions of 3% interest rate and that plantation productivity should reach both maximum and mean productivity values of the country, the optimum initial density of the plantations established under *Vacciniosum* and *Oxalidosum* site conditions should be 2000 trees ha^{-1} and 3330 trees ha^{-1} or lower, respectively.

## Discussion and conclusions

Under the interest rate of 2-3% and plantation productivity varying from the mean value to maximum, the initial density of the plantations established under *Vacciniosum* ($H_{100}$ =27 metres) and *Oxalidosum* site conditions ($H_{100}$ = 33 metres) should be 2-3 thousand trees ha^{-1} and 3-5 thousand trees ha^{-1}, respectively.

The dendrometric characters and wood quality parameters were evaluated in the Scots pine plantations of different density that had been established under *Vacciniosum* and *Oxalidosum* site conditions and their age was 25 and 38 years, respectively. Based on these data the mean diameter, height, volume, quality of the butt logs at the age of maturity and harvested volume of wood during the thinnings (commercial harvestings) were determined. For the forecasting of dendrometric characters, the "Models of dynamics of the major stand dendrometric characters" (Kuliešis 1993), that currently are most precise in Lithuania, were used despite Grigaliūnas (1998) indicates the necessity of further improvement of these models. Correction of these models, depending on the plantation density (Elfving 1981, Agestam et al. 1998), was applied when the plantation densities reached 6670 and 8000 trees ha^{-1} only. These corrections had no influence on optimisation of the initial plantation density as the optimum densities were lower the mentioned ones.

It has been well documented that the origin of the stand influences their growth and productivity (Kisieliov 1962, Gradeckas 1987, Mikšys 1998 and many others). Gradeckas (1987) has analysed the productivity of the Scots pine stands of natural and artificial origin and has found that the pine stands of artificial origin were taller and produce more timber than the natural ones. The differences in volume between these stands attain even up to 40%.

After evaluation of the productivity all of the Lithuanian Scots pine stands growing under *Oxalidosum* and *Oxalido-myrtillosum* site conditions it was found that at the age of maturity, the productivity of artificially established stands had exceeded that of the stands of natural origin by 17%. In order to expand a scale of evaluation depending on the productivity of the Scots pine stands and reduce or avoid the influence of possible errors occuring in evaluating stand dendrometric characters on the differences in the productivity of the naturally and artificially established stands, the origin (artificial or natural) of the stand, had not been allowed for. Therefore, the defined optimum initial densities of the plantations embrace slightly broader range of productivity.

When evaluating gain of growing up of the stands, a very great role was played by the income obtained

during the final harvesting at the age of tree maturity. Selection of trees to be harvested during the final harvesting and evaluation of their quality were performed in the plantation aged 25 and 38 years. The predominating trees were selected as the trees to be harvested by the final harvesting at their maturity age. It is known that the predominating trees rarely shift their rank (Kairiūkštis 1969, Antanaitis et al. 1986 and many others). Trees - the leaders can be distinguished early in the stands and could be selected reliably already at the age of 8-12 years (Maslakov 1984, 1992, Maslakov & Pankejeva 1986).

The quality of butt logs was evaluated by branch thickness and stem straightness. With exception of the plantation of the initial density of 500 tree ha$^{-1}$, the branches were dead during the evaluation. When evaluating stem straightness, attention had not been payed at the minor (up to 1.5 cm$^{-1}$) curvatures in short distances (up to 1 meter) of the stem as, after Timofeyev (1977), they become overgrown when the tree is growing.

In 1999, the real expenses of establishment, care and protection of the plantations until they get included into forest area in Lithuania varied within 1400-4900 Lt ha$^{-1}$ and the mean expenses reached 2300 Lt ha$^{-1}$. Our calculated expenses of establishment of the Scots pine plantations of mean density slightly differ from the mean ones of the country.

The determined initial densities of the plantations are based on changes in wood quality and stand productivity depending on initial plantation density and current prices of plantation establishment and growing up as well as these of realization of the production. In comparison to other European countries, in Lithuania the expenses for plantation establishment and growing up are lower as well as the prices for the production. Therefore, the increase in them is possibly inevitable which can make corrections in here recommended optimum intial plantation densities if an increase in expenses and in income is uneven.

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# ЭКОНОМИЧЕСКАЯ ОЦЕНКА ВЫРАЩИВАНИЯ СОСНОВЫХ КУЛЬТУР РАЗЛИЧНОЙ ГУСТОТЫ

А. Малинаускас

*Резюме*

Проведен анализ культур в брусничной серии типов леса первоначальной густоты 500, 2000, 3000, 4440, 5000, 6670, 8000 шт. га⁻¹, в возрасте 25 лет, а также в кисличной серии типов леса первоначальной густоты 3330, 5000, 6670 и 8000 шт. га⁻¹, в возрасте 38 лет. Дана оценка качества древесины, а также рассчитана экономическая эффективность выращивания культур сосны различной густоты, созданных в брусничной и кисличной сериях типов леса.

Экономическая эффективность выращивания была определена при дисконтой норме 0%, 2%, и 3%, и при максимальной и средней по Литве продуктивности сосняков. При 2-3% дисконтой норме и от средней до максимальной продуктивности культур сосны, в брусничной серии типов леса ($H_{100}$ = 27 м) оптимальная густота посадки находится в пределах от 2 до 3 тыс. шт. га⁻¹, а в кисличной серии типов леса ($H_{100}$ = 33 м) – от 3 до 5 тыс. шт. га⁻¹.

**Ключевые слова:** сосна, начальная густота культур, экономическая оценка