Economical Evaluation of the Larch Plantations of Different Initial Density

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The 19-year-old test plantations of European larch (*Larix decidua* Mill.), Japanese larch (*Larix leptolepis* Gord.), and their hybrids (*L. decidua* x *L. leptolepis*) of various initial density (500, 1000, 2000, 3000, 5000, 10000 trees ha^{-1}) that had been established at the **Dubrava** Experimental Forest Enterprise by using of the square design were studied.

It was found that the **quality** of tree butt-logs tended to increase with increased initial density up to 3000 trees ha^{-1}. At the mentioned density it is possible to select the fast growing trees that will have the butt-logs of the highest quality class in the future. The effect of cultivation of larch plantations of various initial densities was computed at the interest rates of 0-4% and assuming that the productivity of the plantations should be moderate or close to maximum. It was found that the highest economical effect of cultivation of larch plantations could be achieved when the initial density was 2000-2500 trees ha^{-1}.

Key words: larch, initial density, wood quality, economical evaluation.

Introduction

Larch is often considered as a tree of the future. This title comes due to fast growth, high productivity, good physical-technical wood properties and wide possibilities of wood application. Mainly, European and Japanese larch species as well as their hybrids deserve this title. These trees exhibit fast growth not only within their natural ranges of distribution but outside them as well. Larch often exceeds indigenous tree species by productivity and technical wood properties; therefore, it is often used to establish the plantations in Great Britain, France, Germany and other countries (Schober 1987, Scohy 1990, Malcolm 1997).

Larch is very productive species not only in Europe, but in North America too. For instance, in the state of Wisconsin, the USA, the 50-year-old plantations of European and Japanese larch species reached the mean height of 30 meters and more. The mean diameter at the same plantations was 40 cm (Einspahr et al. 1984). Because of their beauty the Forestry Commission of Great Britain called larch species "the trees for all seasons". The Commission also stresses their particular role in industrial forests as these species well contribute to the promotion of forest plantations to the desirable multi-purpose forests of the 21-rst century (Forestry commission 1991).

European and Japanese larch species as well as their hybrids show fast growth and high productivity in Lithuania as well where they exceed considerably the indigenous conifers and even soft deciduous tree species (Jankauskas 1954, Daraškevičius 1988). In Lithuania, along with the mentioned authors, Tuminauskas and Ramanauskas (1983), Andriuškevičienė and Ramanauskas (1985), Malinauskas and Suchockas (1995, 1997) have studied the growth and productivity of various larch species, European and Japanese larch species' breeding aspects their interspecific relationships with the other tree species in the mixed plantations, technological subjects of seedling cultivation and establishment of plantations, etc. However, too little attention had been paid to the studies on the initial density of the larch plantations. Such experiments had been performed in various countries and a relationship between the initial density and wood quality was found (Persson 1976, 1977, Huuri and Lähde 1985, Johanson 1992, Röhring 1995). Nevertheless, the results of the studies on optimization of the initial plantation density maximizes the financial rate of return show that the plantations of low or moderate density are superior to dense ones (Simo 1978, Lauri 1982, Turkevič et al. 1984, Lohmander 1994, Gong 1998, and others). Although the demand for wood of higher quality in the market is greater (Persson 1977, Niemistö 1995, Björklund and Hörnfeld 1996), relatively slight differences in price for the sortments of different quality classes do not promote the production of the higher quality wood and, thus establishment of the plantations of high initial density.

The aim of these studies was to evaluate wood volume and quality at the plantations of different initial density and optimize the initial density of the larch plantations under the assumption of their 50-year rotation period maximizes the financial rate of return.

Materials and methods

The 19-year-old test plantations of European larch (Larix decidua Mill.), Japanese larch (Larix leptolepis Gord.), and their hybrids (L. decidua x L. leptolepis) of various initial densities that had been established at the Vaišvydava forest district of the Dubrava Experimental Forest Enterprise were studied. European larch, Japanese larch and their hybrids make up 30%, 3%, and 67% of the total composition of species, respectively. Comparing with the European larch trees, the hybrid individuals differed insignificantly from them by growth rate, however, they were negligibly more crooked (5-7%).

The plantations were established by planting 2-year-old seedlings in the formerly clear-cut area of Norway spruce stand under Oxallidosum site conditions in unprepared soil. The initial density of the plantations was 500, 1000, 2000, 3000, 5000, and 10000 trees ha^{-1}. The plantations were established following a square design with two replications. Each plot occupies an area of 0.20 ha with the exception of the plots of 5000 and 10000 trees ha^{-1} of initial density. Their size was 0.10 ha each.

The diameter for all trees has been measured and the height of 1-4 trees in each thickness' class estimated. The number of trees per 1 hectare has been calculated as well as other dendrometric parameters have been recorded. In each density variant 50 trees have been selected. For them the diameter of the thickest branch in the length of 5.0 m. of the butt log, has been measured stem curviness (cm m^{-1}) estimated and potential crop trees (360 trees ha^{-1}) selected. Based on the parameters of stem curviness and branch diameter, a quality class for butt logs has been estimated according to standards LST L ENV 192-2-2001, IST 9325773-5: 2001 and IST 93 25 773-8:2001.

Selection of the potential crop trees that will reach an age of 50 years and evaluation of their quality was performed at their age of 19 years. As the candidates to reach an age of 50 years, the straightest trees growing fastest and having the thinnest branches, i.e. prevailing trees in the stand or moderate ones were selected. It has been recorded that prevailing trees of class "A" shift their ranking imperceptibly (Kairiūkštis 1969, Antanaitis et al. 1986). Trees-leaders distinguish in the stands early and might be well identified at the age of free growth, i.e. at the age of 8-15 years (Maslakov 1984, 1998, Maslakov et al. 2001).

A growth prognosis (mean diameter, height and volume) of larch plantations of various initial density until age of 50 years was calculated according to the data on the growth of such larch plantations (Suchockas and Malinauskas 1997). The number of trees to be harvested during thinnings was calculated based on number of trees to be existing in the plantations aged 5-50 years when they have a maximum volume increment (Malinauskas 1994) as well as based on the dynamics of natural change in tree number in the larch plantations (Suchockas and Malinauskas 1997). The dynamics of a change in tree number at the plantations of various initial densities is presented in Figure 1. The mean diameter and heights of the trees to be harvested during thinnings were evaluated based on the tables "The dynamics of a change in the major dendrometric parameters of the stand, Scots pine" (Kuliešis 1993). By using of the tables of the structure of tree volume (Kuliešis et al. 1997), the structure of wood to be harvested during thinnings was determined. Based on these data as well as on the requirements by the standards (LST L ENV 1927-2-2001; IST 9325 773-5:2001; IST 9325773-8:2001), sortment structure of the wood to be harvested was determined too.

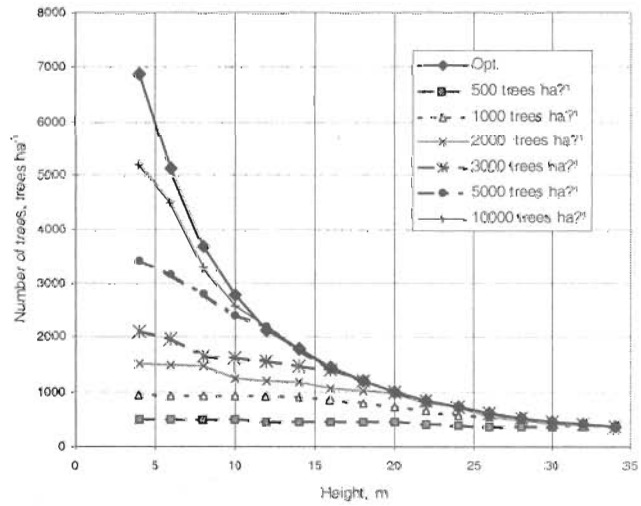

Figure 1. Maintaining the number of trees by thinings in larch plantations of various density

Technological costs of plantation establishment has been calculated according to the methods that are used for such purposes (Mizaras and Danusevičienė 1999).

Economical effect of stand cultivation has been calculated according to equation 1 (Wenger 1984):

$$PNW = \sum_{t=0}^{u}\left[\frac{(R + -Ct}{(1+i)^t}\right] \quad (1)$$

where: PNW - present net worth; R - revenue; C - cost; i - interest rate; n - investment period; t - annual cost incurred or revenue received.

When calculating the revenue for wood, mean prices of Scots pine sortments in January 2002 (I-rst group for fuel wood, MEC News 2002) and mean cost of forest harvesting and transportation to the road in the period of January - September were used (MEC News 2001).

Economical effect of cultivation of plantations of various initial densities was calculated for the plantations that reach close to maximum productivity and mean productivity. The data on the dynamics of the growth of larch plantations by Suchockas and Malinauskas (1997) were obtained when measuring the plots where tree growth was fastest and that were most homogeneous. Therefore, the forecasted parameters of larch plantations of various initial densities at the age of 50 years are close to the maximum ones. The mean productivity of larch plantations was considered to be equal to that of Scots pine plantations in Lithuania, i.e. 70% of the maximum one.

Costs of establishment of forest plantations do not confine to costs of establishment, care and protection during the first several years. Annual costs for plantation care include fire protection, sanitary protection, establishment and maintenance of the road net, protection against arbitrary use and additional cost. The latter ones were calculated according to the generally used methods (Mizaras and Danusevičienė 1999). On the other hand, indirect costs of plantation establishment and care are only slightly influenced by plantation initial densities, therefore, economical effect of cultivation of larch plantations of various densities was calculated both including and excluding these costs.

Results

It was found that the mean diameter decreased, mean height initially tended to increase but later decreased too and stem volume increased at the unthinned 19-year-old larch plantations (Table 1).

A forecasted dendrometric characteristics of the plantations at the age of 50 years after, if necessary, maintaining the number of trees (cf. Figure. 1) by thinnings, is presented in Table 2. When forecasting the mean stand diameters, tree heights and volumes at the age of 50 years for the plantations of 5000 and 10000 trees ha^{-1} of initial density, the possibilities provided by the plantations of higher initial densities to select the trees of faster growth during the thinnings had not been considered because both published data and these being at our disposal were not satisfactory to evaluate such possibilities in this study.

Table 1. Dendrometric characteristic of larch plantation of different initial density at age 19 years

Initial density, trees ha^{-1}	The number of trees, trees ha^{-1}	DBH, cm	Height, m	Stem volume, m^3ha^{-1}
500	460	18.5	12.0	99
1000	930	17.5	12.8	183
2000	1025	16,7	15.9	199
3000	1400	15.7	17.0	258
5000	1580	14.6	16.8	269
10000	1700	13.2	15.9	278

Table 2. Forecasted dendrometric characteristics of the plantations of different initial densities at the age of 50 years

Initial density, trees ha^{-1}	Mean height,m	DBH,cm	Volume, m^3ha^{-1}	Harvesting part of the stand during the thinnings, m^3ha^{-1}
500	31.1	35.2	594	27
1000	32.4	33.0	656	128
2000	33.9	32.4	685	227
3000	33.9	32.4	685	247
5000	33.9	32.4	685	262
10000	33.9	32.4	685	278

The plantation establishment and care costs tended to increase for the plantations of higher initial densities (Table 3). The establishment costs for plantations of 500 trees ha^{-1} of initial density (816 Lt. ha^{-1}) were 2.4 and 9.5 times lower than those for the plantations where the initial density was 2000 and 10000 trees ha^{-1}, respectively. Comparing the total stand productivity at the age of 50 years in the plantations of the above-mentioned densities, it increased only in 47 and 59%, respectively. At the plantations of low

Table 3. Cost of establishment and care of the plantations Lt ha^{-1}

Initial density, trees ha^{-1}	Soil preparation	Planting and additional planting	Care of plantation	Totally
500	384	331	101	816
1000	384	663	152	1199
2000	384	1325	241	1950
3000	384	1985	320	2689
5000	384	3313	434	4131
10000	384	6626	745	7755

initial densities, the highest part of the costs were made by those for site preparation and seedlings while seedling costs made the highest part of costs at the plantations of high densities. Due to the fast growth of the larch trees, the care costs were slight and approximately made up just 12% of the total costs of plantation establishment.

Based on the evaluation at the age of 19 years, the distribution of the butt logs of the potential crop trees by quality classes is given in Table 4. At the plantations of 500 trees ha^{-1} of initial density the butt logs belonged to the quality classes of "B", "C", "D", and "fuel wood", whilst at the plantations of 3000 trees ha^{-1} and higher initial density they belonged exceptionally to the class "B". Moreover, the trees having high quality butt logs showed faster growth at the plantations of higher initial densities than at those of lower densities.

Table 4. Distribution of butt logs by the quality classes.

Initial density, trees ha^{-1}	Quality classes				
	A	B	C	D	Fuel wood
500		52	30	13	5
1000		60	40		
2000		90	10		
3000		100			
5000		100			
10000		100			

The economical effect of cultivation of larch plantations of various densities was evaluated at the interest rates of 0%, 2%, 3%, and 4%. One economical effect was calculated including only technological costs of plantation establishment and cultivation while another one included all costs. Also, economical effect was calculated for the plantations, the productivity of which was close to maximum and moderate (Table 5). At the interest rates of 2 - 4%, the highest economical effect, both including and excluding indirect costs from their computations, was obtained for the plantations of 2000 trees ha^{-1} of initial density. At the 0% of interest rate, the plantations of 3000 trees ha^{-1} of initial density had the highest economical effect.

Discussion and conclusions

It was found that the costs of establishment and care of forest plantations depended on the initial density. The cultivation costs increased for the plantations of increased initial density (Lohmander 1994, Gong 1998, Zhou 1999). Increasing initial density of the larch plantations influenced higher costs basically due to seedling costs while costs of the plantations of high initial density as well as those for pre-commercial harvestings arose due to thinning of too dense plantations. The calculated costs for establishment and care of the larch plantations of 2000 and 3000 trees ha^{-1} of initial densities were estimated at 1960 and 2689 Lt. ha^{-1}, respectively and were close to the mean costs of plantation establishment in Lithuania that are estimated at 2300 Lt. ha^{-1} (General Forest Enterprise 2000).

Table 5. Economical effect of growing Larch plantations of varions densities (Lt ha^{-1}) of different interest rates.

Initial density, trees ha^{-1}	Interest rate, %			
	0	2	3	4
Potentially produktivity Excluding indirect cost				
500	50238	48638	47040	44485
1000	67311	66913	65798	63609
2000	77878	78264	77288	74869
3000	78851	78062	75909	71342
5000	77330	74000	69138	60698
10000	73640	64044	53022	34419
Including indirect cost				
500	40520	36999	33794	28855
1000	49538	52288	48991	43544
2000	55774	60000	55570	48060
3000	56292	58355	51983	41102
5000	53777	51754	41480	24325
10000	47961	36232	16478	-16085
Mean productivity Excluding indirect cost				
500	34862	33247	31641	29077
1000	46698	45731	44268	41648
2000	53870	53070	51320	47929
3000	64329	52332	49386	43884
5000	52772	48204	42707	33122
10000	49042	38176	26338	6712
Including indirect cost				
500	27517	24036	20843	15910
1000	33658	24275	30726	24971
2000	37636	38762	33849	25727
3000	37715	36717	29881	18429
5000	35216	30170	19431	1782
10000	34034	14717	-5513	-38526

By increasing the initial density of the larch plantations up to 3000 trees ha^{-1}, the quality of butt log was higher too. Many publications exist about the influence of the initial density on wood quality and they report similar results (Person 1976, Vyskot 1978, Johansson 1992, 1993, Lindstrom 1996, Simpson and Denne 1997 and many others). At the larch plantations, stem curviness rather than branch thickness had stronger influence on wood quality. At the initial density of 3000 trees ha^{-1} it is possible to select the potential crop trees having the butt logs of exceptionally "B" quality class. The only reason for considering the butt logs of quality class "B" was the fact that they still had some branches at the age of 50 years. According to the other parameters they suit quality class "A", therefore, the butt logs of the potential crop trees would have higher quality if they were pruned at the age of 20-30 years.

The economical effect of cultivation of larch plantations at the 0-4% interest rate was positive and high. The only exception was observed for the plantations of 10000 trees ha^{-1} of initial density when indirect costs were included into calculations. In this study calculated economical effect considerably exceeded the values computed by Mizaras (2000) for other tree species and those by Malinauskas (2001) for the Scots pine plantations of various initial densities. This resulted from high productivity and short rotation period of larch plantations as compared to other coniferous and deciduous tree species. Larch also differed from the soft deciduous tree species by higher wood price.

For the plantations of 10000 trees ha^{-1} of initial density, the calculated economical effect was negative even at their maximum productivity and interest rate of 4%. It was also negative when the productivity was moderate and interest rate was 3%. In both cases, all costs were included into calculations.

In the future, interest rate of 2-3% and moderate or slightly higher plantation productivity, especially in the abundant agricultural areas, are most presumable. At the given interest rate and plantation productivity as well as assuming that difference in economical effect between the plantations of 1000 and 2000 trees ha^{-1} of initial density and those of 2000 and 3000 trees ha^{-1} makes up 9 - 37% and 1 - 12%, respectively, the optimum initial density of the larch plantations is 2000 - 2500 trees ha^{-1}. The plantations of European larch due to straighter stems of this species (Malinauskas and Suchockas 1997) should be established at the density of 2000 trees ha^{-1} while the density of hybrid larch plantations should be 2000 trees ha^{-1}. These initial densities of the larch plantations correspond to or are higher than those recommended in Great Britain (approximately 900-2500 trees ha^{-1}) and France (1111-2500 trees ha^{-1}) but are lower than those recommended in Germany 2500-3300 trees ha^{-1} (Frimsdorf and Magnussen 1980, Benson 1981, Petri 1987, Scohy 1990, Forestry Commission 1991).

As it has been pointed out, the larch butt logs of quality class "B" cannot be assigned to quality class "A" due to branchiness. Currently, the difference in price for sawn logs of quality classes "A" and "B" is estimated at up to 35-40 Lt. m^{-3} (MEC News, 2002). The costs for pruning of butt logs of the potential crop trees should not exceed 2-3 Lt. m^{-3}. Including interest rate for the period of 20-30 years, these costs still should not exceed 4-5 Lt. m^{-3}. Thus, pruning of the potential crop trees might increase the effect of cultivation of larch plantations considerably.

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ЭКОНОМИЧЕСКАЯ ОЦЕНКА ЛИСТВЕННИЧНЫХ КУЛЬТУР РАЗЛИЧНОЙ НАЧАЛЬНОЙ ГУСТОТЫ

А. Малинаускас

Резюме

Изучались 19-летние культуры различной густоты (500, 1000, 2000, 3000, 5000 10000 шт га $^{-1}$ лиственницы европейской (*Larix decidua* Mill.), японский (*Larix leptolepis* Gord.) и гибридной (*L.decidua x L.leptolepis*) произрастающие в Дубравском экспериментально-учебном лесном предприятии. Размещение посадочных мест квадратное, тип леса кисличный.

Установлено,что при увеличении начальной густоты культур до 3000 шт га$^{-1}$ качество первичных бревень деревьев будущего улучшается. При указанной начальной густоте культур возможен отброр деревьев будущего имеющих первычные бревна наивысшего качества. При средней или близкой к максимальной продуктивности и процентных денег 2-3% оптимальная начальная густота лиственичных культур находится в пределах от 2000 до 25000 шт га $^{-1}$.

Ключевые слова: лиственница, начальная густота культур, качество древесины, экономическая оценка.