Effects of Artificial Regeneration Methods on Mortality, Growth and Shape of Oak Seedlings in a Central European Oak-Hornbeam Stand

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Abstract – This paper analyses the results of an artificial regeneration experiment carried out in an oak-hornbeam stand. The effects of initial seedling density (10200, 14300, 35700 stems per hectare), spacing geometry (140 cm x 70 cm, 240 cm x 40 cm), chemical (with Erunit and Nabu) and mechanical weeding of pedunculate (*Quercus robur*) and sessile oak (*Quercus petraea*) were examined at the age of eight years. The mortality of *Q. robur* seedlings was independent of the initial density but that of *Q. petraea* increased with it. Height and diameter growth of both species significantly decreased with the density, and the values of the diameter-to-height ratios (DHR) became smaller as the density increased. At approximately the same seedling density the mortality was lower but the seedlings were shorter, thinner and the values of DHR were smaller if the distance between stems was much lower than that between rows. Mechanical or chemical weeding did not affect considerably seedling mortality, growth or shape in any of the spacing types.

weeding / *Quercus petraea* / *Quercus robur* / seedling development / seedling survival / spacing

Kivonat – Mesterséges felújítási eljárások hatása az újulat öngyérülésére, növekedésére és alakjára egy közép-európai gyertyános-tölgyesben. A tanulmány egy gyertyános-tölgyesben végrehajtott mesterséges felújítási kísérlet eredményeit mutatja be. Kocsányos (*Quercus robur*) valamint kocsánytalan tölgy (*Quercus petraea*) esetében a felújítás nyolcadik évében vizsgáltam a kiindulási csemeteszámnak (10200, 14300, 35700 db/ha), a hálózat geometriájának (140 cm x 70 cm, 240 cm x 40 cm) valamint vegyszeres (Erunit és Nabu vegyszerekkel) és mechanikus ápolásoknak a hatását. A kocsányos tölgy öngyérülése nem függött a kiindulási csemeteszámtól, ugyanakkor a kocsánytalan tölgyé a csemeteszámmal emelkedett. A csemeteszám emelkedésével a magassági növekedés ill. a vastagodás mindkét fafaj esetében csökkent, és a csemeték nyurgábbá váltak. Megközelítőleg azonos kiindulási csemeteszám mellett a tőtávolság csökkentésével (és így a sortávolság növelésével) az újulat öngyérülése csökkent, ugyanakkor a csemeték magassága és vastagsága is csökkent, valamint felnyurgultak. A mechanikus ill. a vegyszeres ápolás egyik hálózati típus esetében sem befolyásolta jelentősen a csemeték növekedését ill. alakját.

ápolás / *Quercus petraea* / *Quercus robur* / újulat fejlődése / újulat mortalitása / ültetési hálózat

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1 INTRODUCTION

One of the most important periods in the life of managed forests is the regeneration. It determines the subsequent development of the growing stand (Ovington – MacRae 1960). Thus, the regeneration technique must be chosen with special care from ecological and economical points of view.

The costs of regeneration strongly correlate with the biological aspects of the applied technique. Methods less suitable for seedling survival and development are more expensive while planting must be repeated and the regeneration period is longer. Costs of seeds or seedlings are possibly high if regenerating artificially. Thus, determining the optimal seed or seedling number is of great importance. To do this, four questions must be answered: How does seedling density influence 1. the mortality and 2. the growth of the developing stand as well as in long-term 3.the shape and 4. the wood structure of the individual trees?
In artificial oak regenerations, wide spacing with low number of seedlings was often applied in Central Europe (Weaver – Spiecker 1993). However, using high number of seeds or seedlings with closer distance between stems can be more advantageous from three points of view (Varga 1966, Savill and Spilsbury 1991):

1. the canopy of the growing stand closes faster so weed competition decreases sooner;
2. the shape of the seedlings may become better while forking is inhibited due to the shading of the neighbouring seedlings;
3. there is a greater supply for natural or artificial selection.

Furthermore, smaller distances between stems can facilitate height growth to some extent in the case of some species (Fekete 1938, Szodfridt 1959). It is also clear that more seedlings can utilize site productivity better as long as spacing is not too dense which leads to a greater intraspecific competition and consequently to slower seedling growth (Szodfridt 1959, Harmath 1961, Solymos 1983, Harkai 1987, Kolb – Steiner 1990). Other disadvantages of denser spacing are its obviously higher costs and technical difficulties with silvicultural treatments (weeding, cleaning; Varga 1966). The effects of spacing on oak seedling survival and growth are still poorly known.

Costs of weeding can be high at both artificial and natural regeneration. At the beginning of regeneration herbs can influence survival and growth of seedlings in two main ways (Magyar 1933): by shading (competition for light) and by root competition (competition for water; Harmer et al. 2005, Harmer – Morgan 2007). Thus, chemical or mechanical weeding can facilitate seedling survival and growth of oak as well as those of other tree species (Ovington – MacRae 1960, Jarvis 1964, Csesznák 1980, Kolb et al. 1990, Kolb – Steiner 1990, Collet – Frochot 1996, Collet et al. 1996, Chaar et al. 1997, Collet et al. 1997, Collet et al. 1998, Kelly 2002, Coll et al. 2003). There is an important difference between the chemical and mechanical protection. While in the former case usually the whole plant dies with its root system, in the latter in most cases only the above-ground part is killed. In this way shading effect decreases but root competition does not. So seedling growth may remain inhibited (Davies 1985, Löf 2000). On the other hand, weed competition does not hinder seedling development by all means (Madsen 1995). Furthermore, in some cases even the total protection from root competition of herbs did not lead to higher seedling growth intensity (Szappanos 1969).

Weeding experiments of oak were usually quite short-term analyzing data of 1-4 years (Szappanos 1969, Collet and Frochot 1996, Collet et al. 1996, Chaar et. al 1997, Collet et al. 1997, Löf 2000). Some studies (Collet et al. 1998, Kelly 2002) were longer-term, but the combined effects of different weeding treatments and spacing types were not examined.

The aim of the present study is to determine the effects of different spacing types and weeding treatments on oak seedling survival and growth simultaneously in a sessile oak–

hornbeam and a pedunculate oak–hornbeam stand: How do spacing geometry, initial seedling density, mechanical and chemical weeding influence the mortality, growth and shape (lankiness) of the seedlings?

2 MATERIALS AND METHODS

2.1 Study area

The study stand (subcompartment Káld 46 B, approximately 11.1 ha, 47°09'N, 17°00'E) is growing on rusty brown forest soil, 200 m above sea level. The climate is characterized by a diagram (*Figure 1*). The whole study area was fenced against game in 1994.

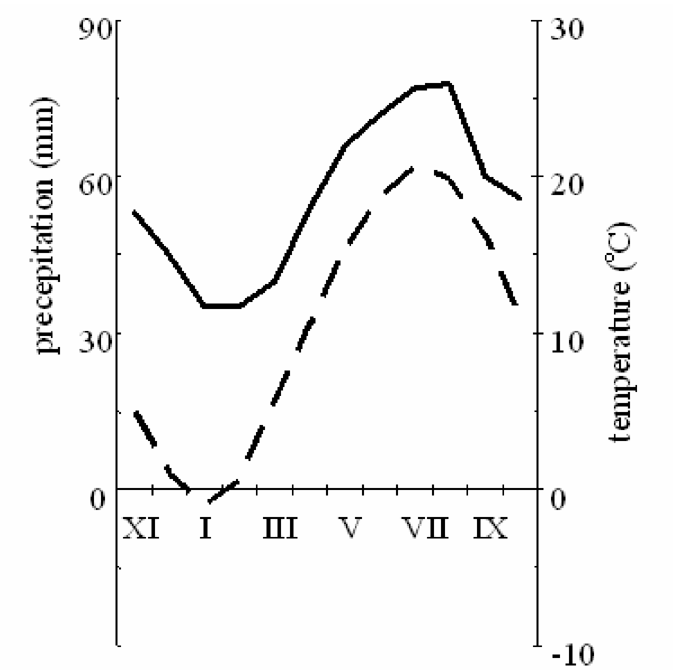

Figure 1. Climate diagram for characterizing the study stand. Monthly precipitation (solid line) and temperature (broken line) were measured at two nearby meteorological stations, Káld and Pápa, respectively from 1901 to 1950. Source: Kakas (1967).

The mixed parent stand consisted of sessile oak (*Quercus petraea*, net area rate 32% – data of the Hungarian National Forest Service), turkey oak (*Quercus cerris*, 24%), hornbeam (*Carpinus betulus*, 24%) and pedunculate oak (*Quercus robur*, 20%) before starting the regeneration. The closure of the parent stand was approximately 95%. At this time the stand was nudum (i.e. the ground vegetation was very sparse).

In the initial stage of regeneration high cover of fleabane (*Erigeron canadensis*) was characteristic. Later on thistle species (*Cirsium sp.*) and *Erigeron annuus* proliferated. From the third year on bushgrass (*Calamagrostis epigeios*) occurred in high abundance. Finally, by the fifth year the cover of blackberry (*Rubus spp.*) has reached high values in some spots endangering seedling survival and growth.

2.2 Silvicultural treatments

The whole stand was divided into 12 blocks of approximately identical size (*Figure 2*). Blocks No. 1-2, 5-8, 11-12 are included in the present study.

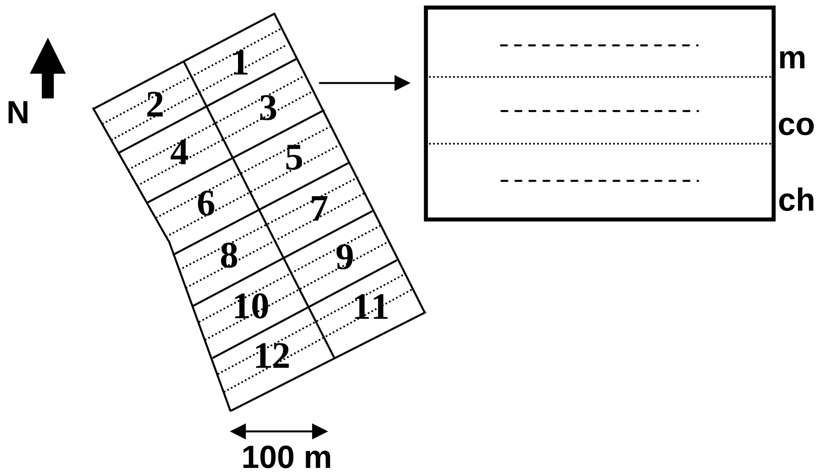

Figure 2. Experiment design. The study stand was divided into 12 blocks of approximately identical size. Each block consists of three plots in which different weeding treatments (mechanical weeding – m; control – co; chemical weeding – ch) were applied. Seedlings were sampled along 50 m long transects (broken line) in the middle of each plot.

No site preparation was applied on the study area before planting. One year-old seedlings of *Quercus robur and Q. petraea* were planted in different spacing types in the spring of 1995 (*Table 1*). One of the applied densities (14 300 stems per hectare) is that which is recommended by Danszky (1963) for oak-hornbeam stands growing in this region of Hungary.

Table 1. Spacing types of artificial regeneration

Blocks	Species	Row dist. (cm)	Stem dist. (cm)	No. stems per hectare
1.	Q. rob.	140	70	10200
2.	Q. pet.	140	70	10200
5.	Q. rob.	240	40	10400
6.	Q. pet.	240	40	10400
7.	Q. rob.	140	50	14300
8.	Q. pet.	140	50	14300
11.	Q. rob.	140	20	35700
12.	Q. pet.	140	20	35700

At the beginning of the regeneration all blocks but No. 11 and No. 12 were sprayed with Erunit. Afterwards, every block was divided into three plots in accordance with the applied weeding method (one control plot, one plot weeded chemically and one plot weeded mechanically). Seedlings of goat willow (*Salix caprea*) and aspen (*Populus tremula*) were cut in all plots in 1999. In the plots weeded mechanically the above-ground biomass of the competing vegetation was removed in July 1997 and in July 1998.

Chemical weeding was carried out with chemicals Erunit and Nabu in March 1997 and in June 1998, respectively. The second treatment was not performed in blocks No. 1 and No. 2 due to unfavourable weather conditions. Because of the high cover of bushgrass Nabu had to be sprayed in blocks No. 11 and No. 12 in May 1997. Erunit inhibits the germination of mono- and dicotyledons alike for three-four months. One liter Erunit contains 300 g acetochlor, 200 g atrazine and 30 g antidote AD-67. The applied concentration was 7 l/ha. Nabu kills monocotyledons selectively. The agent of Nabu is sethoxydim (12.5%). Nabu was sprayed in concentration of 4 l/ha. Both chemicals can reduce root competition. In 2000 woody species were weeded out in all plots. Afterwards, further weeding treatments were not necessary.

2.3 Sampling

Sampling was carried out in 2003 and started with a pilot sampling to analyze the effect of sample size on the value of the mean of the dependent variables (seedling height and diameter). That is, much more seedlings were sampled in some chosen plots (on which the variance of seedling height and that of seedling diameter were the highest according to visual estimation) than the estimated required minimum. From the data the fluctuation of the mean value with increasing sample size was determined. The sampling size from which the fluctuation was smaller than 5% was considered as the required minimum sample size. Based on the obtained data heights and diameters at breast height of all seedlings were measured along 50 m long transects in the middle of each plot (*Figure 2*) except for plots of blocks No. 6, No. 11 and No. 12. In the latter plots transects were divided into 10 m long sections due to the high number of seedlings. Heights and diameters at breast height of all seedlings were measured along the two end and the middle sections.

2.4 Data analysis

The shape of the seedlings was characterized with the quotient of the diameter and the height (d/h). Since both diameter and height were expressed in meter the quotient has no dimension. Data were evaluated with analysis of variance using BIOMstat 3.3 program (2002). For checking normality and homogeneity of variances the Kolmogorov-Smirnov and F-max statistics (Hartley 1950) as well as log-anova tests (Martin – Games 1977) were used, respectively. Where assumptions of parametric ANOVA could not have been met Kruskal-Wallis ANOVA was applied. The effects of weeding were studied in each block (i.e. in the case of each spacing type, *Table 1*) separately.

3 RESULTS

3.1 Effects of seedling density at the same row distance

Considering all plots, the average mortality of pedunculate and sessile oak was similar, 21.3% and 26.4%, respectively. Mortality of pedunculate oak doesn’t correlate strongly with the initial seedling number in any of the plots (*Table 2a, b*). In contrast, mortality of sessile oak seems to increase with it in every plot. Height and diameter growths as well as DHR of the seedlings decreases significantly as seedling number increases (*Table 2a, b*). These effects are similar in the cases of both oak species and all weeding types.

3.2 Effects of spacing geometry at the same seedling density

Seedling survival was higher in all but one plots in which the differences between the two distance types (distances between rows and distances between stems) were greater (*Table 3a, b*). On the other hand, seedlings of both species were significantly shorter, thinner and DHR values were higher in these plots.

Table 2a. Effects of initial seedling number on mortality, growth and shape of Q. robur seedlings at row distance of 140 cm. The age of the regeneration was 8 years.

Weeding	No. stems per hectare	n	Mortality (%)	h (cm)	d (mm)	(d/h) x 10^{-3}
me	10200	53	26	380** (89)	34.5** (14.3)	8.8 (3.0)
me	14300	78	22	330 (61)	27.1 (10.9)	8.0 (2.3)
me	35700	112	25	243** (73)	16.6** (9.9)	6.2** (2.8)
co	10200	62	13	342 (73)	28.9 (11.5)	8.2 (2.1)
co	14300	73	27	344 (75)	28.0 (11.2)	7.8 (2.3)
co	35700	121	19	262** (77)	16.3** (9.9)	5.6** (2.5)
ch	10200	48	33	350** (74)	31.2** (13.1)	8.6** (2.4)
ch	14300	74	26	291 (84)	21.8 (11.5)	6.9 (2.6)
ch	35700	120	20	279 (83)	16.5** (9.8)	5.4** (2.5)

Table 2b. Effects of initial seedling number on mortality, growth and shape of Q. petraea seedlings at row distance of 140 cm. The age of the regeneration was 8 years.

Weeding	No. stems per hectare	n	Mortality (%)	h (cm)	d (mm)	(d/h) x 10^{-3}
me	10200	53	26	345** (79)	31.0** (12.8)	8.6** (2.7)
me	14300	73	27	275 (81)	19.7 (11.3)	6.5 (2.9)
me	35700	102	32	250* (76)	16.1* (10.4)	5.8* (2.7)
co	10200	53	26	346** (66)	30.1* (12.1)	8.4 (2.3)
co	14300	72	28	303 (84)	24.7 (13.5)	7.5 (3.0)
co	35700	95	37	269** (68)	17.4** (9.7)	5.9** (2.4)
ch	10200	59	17	352** (59)	31.2** (10.2)	8.7** (2.0)
ch	14300	83	17	269 (77)	19.7 (10.6)	6.8 (2.6)
ch	35700	80	47	247* (76)	14.9** (8.3)	5.7** (2.4)

Quotients in the last column are the averages of quotients calculated for each seedling. Standard deviations are showed in parentheses. Plots in which 14300 seedlings were planted were compared to the two other plots in the case of each weeding treatment. If the difference was significant it is indicated only at data of the two latter plots. h – average height of the seedlings; d – average diameter at breast height of the seedlings; me – plots weeded mechanically; co – control plots; ch – plots weeded chemically; *Q. rob.* – *Quercus robur*; *Q. pet.* – *Quercus petraea*; * - $p<0.05$; ** - $p<0.01$.

Table 3a. Effects of spacing geometry on mortality, growth and shape of 8-year old Q. robur seedlings.

Weeding	Spacing (cm x cm)	n	Mortality (%)	h (cm)	d (mm)	(d/h) x 10^{-3}
me	140 x 70	53	26	380 (89)	34.5 (14.3)	8.8 (3.0)
me	240 x 40	111	11	300** (70)	24.5** (12.1)	7.7* (2.8)
co	140 x 70	62	13	342 (73)	28.9 (11.5)	8.2 (2.1)
co	240 x 40	114	9	291** (75)	24.0** (11.8)	7.8 (2.8)
ch	140 x 70	48	33	350 (74)	31.2 (13.1)	8.6 (2.4)
ch	240 x 40	94	25	324 (77)	26.3* (12.3)	7.7* (2.4)

Table 3b. Effects of spacing geometry on mortality, growth and shape of 8-year-old Q. petraea seedlings.

Weeding	Spacing (cm x cm)	n	Mortality (%)	h (cm)	d (mm)	(d/h) x 10^{-3}
me	140 x 70	53	26	345 (79)	31.0 (12.8)	8.6 (2.7)
me	240 x 40	66	12	288** (70)	23.4** (11.5)	7.6 (2.7)
co	140 x 70	53	26	346 (66)	30.1 (12.1)	8.4 (2.3)
co	240 x 40	66	12	305** (73)	23.7** (11.4)	7.3* (2.5)
ch	140 x 70	59	17	352 (59)	31.2 (10.2)	8.7 (2.0)
ch	240 x 40	48	36	299** (69)	23.9** (12.3)	7.5** (2.4)

Standard deviations are showed in parentheses. Significance level is indicated only at the data of plots of spacing 240 cm x 40 cm. For abbreviations see *Table 2*. * - $p<0.05$; ** - $p<0.01$.

3.3 Effects of weeding

Weeding did not improve seedling survival of any of the two oak species in any of the spacing types (*Table 4*). On the contrary, in some blocks survival of pedunculate oak seemed to decrease due to weeding. Seedling growth was not promoted considerably either by mechanical or chemical weeding. In some blocks (No. 7, No. 8, No. 11 and No. 12; *Table 4*) seedlings, which were weeded ("w-seedlings") were even significantly shorter and thinner than seedlings, which were not weeded. In contrast, in some other blocks (No. 1, No. 2 and No. 5) "w-seedlings" are significantly taller and thicker though most of these differences are not important from silvicultural point of view. Weeding practically didn't influence seedling shape.

Table 4. Effects of weeding on mortality, growth and shape of oak seedlings, at the age of 8 years

Blocks	Weeding	n	Mortality (%)	h (cm)	d (mm)	(d/h) x 10^{-3}
1.	me	53	26	380* (89)	34.5* (14.3)	8.8 (3.0)
1.	co	62	13	342 (72)	28.9 (11.5)	8.2 (2.1)
1.	ch	48	33	350 (74)	31.2 (13.1)	8.6 (2.4)
2.	me	53	26	345 (79)	31.0 (12.8)	8.6 (2.7)
2.	co	53	26	346 (66)	30.1 (12.1)	8.4 (2.3)
2.	ch	59	17	352* (59)	31.2* (10.2)	8.7* (2.0)
5.	me	111	11	300 (70)	24.5 (12.1)	7.7 (2.8)
5.	co	114	9	291 (75)	24.0 (11.8)	7.8 (2.8)
5.	ch	94	25	324** (77)	26.3 (12.3)	7.7 (2.4)
6.	me	66	12	288 (70)	23.4 (11.5)	7.6 (2.7)
6.	co	66	12	305 (73)	23.7 (11.4)	7.3 (2.5)
6.	ch	48	36	299 (69)	23.9 (12.3)	7.5 (2.4)
7.	me	78	22	330* (61)	27.1 (10.9)	8.0 (2.3)
7.	co	73	27	344 (75)	28.0 (11.2)	7.8 (2.3)
7.	ch	74	26	291** (84)	21.8** (11.5)	6.9* (2.6)
8.	me	73	27	275 (81)	19.7* (11.3)	6.5 (3.0)
8.	co	72	28	303 (84)	24.7 (13.5)	7.5 (3.0)
8.	ch	83	17	269** (77)	19.7* (10.6)	6.8 (2.6)
11.	me	112	25	243* (73)	16.6 (10.0)	6.2* (2.8)
11.	co	121	19	262 (77)	16.3 (9.9)	5.6 (2.5)
11.	ch	120	20	279 (83)	16.5 (9.8)	5.4 (2.5)
12.	me	102	32	250* (76)	16.1 (10.4)	5.8 (2.7)
12.	co	95	37	269 (68)	17.4 (10.0)	5.9 (2.4)
12.	ch	80	47	247** (76)	14.9 (8.3)	5.7 (2.4)
All	me	648	22.6 (7.4)	228 (128)	29.2 (8.5)	7.2 (2.9)
All	co	656	21.4 (9.7)	231 (122)	30.0 (8.0)	7.1 (2.7)
All	ch	606	27.6 (10.5)	221 (122)	29.6 (8.3)	6.9 (2.7)

Plots, which were weeded were compared to the control plots. Significance level is indicated at the data of the former plots. Standard deviations are showed in parentheses. For abbreviations see *Table 2*. * - $p<0.05$; ** - $p<0.01$.

4 DISCUSSION

Higher seedling number increased mortality of sessile oak. The survival of pedunculate oak during the first eight years of the regeneration was determined by other factors not investigated in this study. On the other hand, intraspecific competition between the seedlings inhibited growth and decreased DHR. The results are in accordance with earlier experiments studying other tree species (e.g. Szodfridt 1959, Harmath 1961, Solymos 1983, Harkai1987). Spacing geometry is very important from silvicultural point of view (Varga 1966). If the distance between rows is large enough (e.g. 240 cm) weeding can be mechanised easily. According to the results, however, larger distance between rows didn't compensate for smaller distance between stems at the same seedling density. Because of the small stem distance competition between the seedlings became more intense. This slowed seedling development and decreased DHR. On the other hand, survival of seedlings was much higher in this case. The reason for this phenomenon is not clear. These results disprove the hypothesis of Varga (1966) who concluded that applying large row and small stem distance is just as appropriate for seedling development as the application of equal distances between rows and stems.

Weeding did not improve seedling survival of any of the two oak species. This does not mean that the herb layer could not inhibit seedling development because it is possible that immediately after the weeding occasions "w-seedlings" grew faster. However, in the long-term the effects of the applied weeding treatments are negligible from silvicultural point of view. It must be taken into consideration, however, that weather conditions of 1997 were not favourable for spraying Erunit and this could have influenced the results. Presumably, because of the low precipitation of that year only a small amount of this chemical could infiltrate into the soil leading to low effectiveness of protection. Furthermore, decrease of the cover of bushgrass due to spraying Nabu promoted indirectly the proliferation of blackberry and dicotyledons of tall growth. Thus, weed competition was not reduced effectively enough by this chemical either.

Negative effects of weeding treatments observed in some blocks could be partly the consequence of weeding mistakes (e.g. accidental removal of oak seedlings in plots weeded mechanically). On the other hand, the lower cover of the herb layer in the plots weeded chemically let aspen and goat willow establish and grow.

5 CONCLUSIONS

According to the results, planting approximately 10 000 seedlings per hectare seem to be enough for the successful regeneration. Planting more seedlings slows down the growth and is more expensive. However, later on, effects of the initial seedling number on wood structure must be studied as well (Igboanugo 1990). Considering the same seedling density, from biological point of view it is more advisable to reduce the difference between row and stem distances. It is unnecessary to carry out weeding treatments every year.

The conclusions are valid primarily for stands which have similar stand structure and occur under similar site conditions as the study stands of the present experiment. However, even in these cases further research must be carried out to make the results more general.

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