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EFFECT OF THE DENSITY OF TRANSPLANTS IN REFORESTATION ON THE MORPHOLOGICAL QUALITY OF THE ABOVE-GROUND PART OF EUROPEAN BEECH (*FAGUS SYLVATICA* L.) SIX YEARS AFTER PLANTING

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Abstract

HOUŠKOVÁ KATEŘINA, MAUER OLDŘICH: *Effect of the density of transplants in reforestation on the morphological quality of the above-ground part of European beech (Fagus sylvatica L.) six years after planting.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 6, pp. 1703–1713

Quality of the above-ground part of European beech planted at different densities and spacing patterns for the purpose of artificial forest regeneration was monitored 3, 4 and 6 years after planting. The initial numbers of beech transplants were 5,000 pcs.ha^{-1}, 10,000 pcs.ha^{-1}, 15,000 pcs.ha^{-1} and 20,000 pcs.ha^{-1}. The spacing pattern of transplants was either square or rectangular nearly in all variants: 1.4 × 1.4 m, 2 × 1 m, 1 × 1 m, 0.8 × 0.8 m, 1 ×0.65 m, 0.7 × 0.7 m and 1 × 0.5 m. Conclusions following out from the research are as follows: 1. neither the chosen density of transplants nor their spacing pattern had an essential influence on the after-planting loss or damage of trees; 2. through the planting of larger-diameter transplants it is possible to achieve canopy closure more rapidly as well as faster growth of the plantation; these beech plants keep the edge in growth and quality even 6 years after planting; 3. the higher is the beech plantation density, the less individuals occur in such a plantation with inappropriate stem form; 4. beech plants of the worst quality were found on plots with the lowest initial density of transplants (5,000 and 10,000 pcs.ha^{-1}), yet the number of promising trees was sufficient even there. Thus, none of the experimental numbers of transplants per hectare or spacing arrangements of the European beech transplants can be claimed as inappropriate; however, further monitoring of the plots is necessary.

European beech, artificial regeneration, density of plantations, spacing pattern of transplants, morphological quality of the above-ground part of trees

European beech is a woody species, which used to dominate the natural tree species composition in the Czech Republic. However, it had to give place mainly to spruce through management measures, and its share dropped to less than a fifth of the original representation (Collective, 2010). Towards the end of the last century, an emphasis began to be put on the sustainable development and on the principles of near-natural forest management, mainly due to the health problems of spruce stands, and the share of beech stands or mixed stands with the dominant beech started to grow. The current species' representation is 7.3 %, which is still a low level. The desired share is 18 % and for a comparison, the natural representation of beech is 40 % (Collective, 2010). Taking into account the expected further increase of beech in the species composition of our forests, it is necessary to consider not only the natural regeneration of its stands, which is relatively easily feasible (Indruch, 1985) and often applied in practical use, but also with its artificial introduction into forest stands, in which it is missing now (Samec, 1995; Bartoš and Souček, 2010 etc.). The artificially established stands can bring the same profit and quality as the stands established by other methods (Krahl–Urban, 1963).

Artificial regeneration of all tree species permanently deals with the issue of minimal (resp. optimal) hectare numbers of seedlings and transplants at planting. The question of how many plants per area unit constitutes a long-term dispute between economic and biological aspects of forest regeneration. The rapid increase of hectare numbers in the 1950s (up to 17,000 in beech) resulted in the Czech lands from the use of the low-diameter planting stock (Mráček, 1965; Lokvenc, 1980; Mráček, 1989; Bartoš and Souček, 2010). Compared with the abroad, higher numbers of transplants per hectare were used in our country (Mráček, 1965). The increasing lack of labour force and efforts to enhance economic effectiveness not only in reforestation but also in the subsequent management and tending of plantations led to re-evaluation of the number of transplants (Lokvenc, 1980) and the density of transplants at planting began to decrease. At the end of the 1960s, the hectare number for European beech stabilized around 10,000 individuals per hectare (Mráček, 1989). Today, the Decree No. 139/2004 Coll. stipulates to plant beech on fertile sites at a minimum number of 9,000 pcs.ha^{-1} and on other sites at 8,000 pcs.ha^{-1}; in the case that the beech is used as a reinforcing and soil-improving species, the densities are to be 5,000 pcs.ha^{-1} on fertile sites and 4,000 pcs.ha^{-1} on the other sites). An opinion appears recently, however, that the reduction of the number of transplants has gone so far that high-quality assortments cannot be achieved without pruning in a monoculture (moreover with 20% of permitted loss during the stand establishment).

Experiments with the spacing of European beech have brought ambiguous results. Many experts advise a higher initial density of transplants as optimal. For example, Botev *et al.* established research plots in Bulgaria with different initial densities of transplants ranging from 40,000 to 4,444 pcs.ha^{-1}. After 13 years of regeneration, the best results were recorded on a plot with the initial density of beech transplants 13,333 pcs.ha^{-1} (Botev and Rendakov, 1988). Later it appeared, however, that the beech trees achieved good quality and volume on the other plots, too, and the authors subsequently specified more precisely their recommendation as 12,000–16,000 pcs.ha^{-1} (Botev, 1989) and after 16 years of regeneration to 10,000–20,000 pcs.ha^{-1} (Stiptsov and Botev, 1994). Klein (1983) arrived at similar conclusions. His initial density of beech transplants was 3,300–40,000 pcs.ha^{-1} and he recommended 10,000–20,000 pcs.ha^{-1} (optimum 16,000–20,000 pcs.ha^{-1}). Trauboth (1984) arrived at an optimum initial number of beech transplants 15,000 pcs.ha^{-1}. Muhle and Kappich (1979) established research plots with the artificial regeneration of beech by planting 6,000–20,000 pcs.ha^{-1} and confirmed that the best quality beech occurred at a denser spacing. Similarly, Jeschke (1977) described a successful regeneration of beech with the initial planting density of 16,750 pcs.ha^{-1} with poplars planted between the rows (4.5 × 4.5m) to protect the beech transplants against frost. Krahl–Urban (1963) and Tyshkevich (1976) found a density of 10,000 pcs.ha^{-1} as an optimal amount of beech transplants.

On the other hand, many experts mention as sufficient much lower numbers of transplants per hectare. For example, Heukamp (1999) presents data on the establishment of a beech stand in Garderen (Netherlands) in 1880 at a low number of beech transplants – 1,470 pcs.ha^{-1}, showing a good quality. He maintains that there are more stands in Germany and Netherlands established by planting beech at a low amount, which are of good or sufficing quality. Freist (1980) evaluated a 31-year old beech stand established by planting transplants at 2 × 1 m (5,000 the age of 29 years. He found out that the growth of beech at a relatively low density (3,297 pcs. ha^{-1}) excelled the tabular yield for the given site. He pointed out, however, that the required quality of future trees would call for a frequent and regular elimination of poor-quality individuals. These conclusions led some experts to investigate a lower limit for the number of beech transplants at planting. For example, Guner *et al.* (2010) in Turkey studied the influence of the initial density of European beech on the above- and underground biomass of a 25-year old stand while comparing stands with a higher (7,143 pcs.ha^{-1}) and lower (2,500 pcs.ha^{-1}) initial density. The stand with the higher density achieved better results. Leder and Weihs (2000) studied the growth and quality of 8-year old beeches planted under Scots pine shelters of varied densities. The spacing pattern of beech plants was 4×1 m (2,500 pcs.ha^{-1}), 1.5 × 1 m (6,667 pcs.ha^{-1}), 4 × 0.5 m (5,000 pcs.ha^{-1}) and 2 × 1 m (5,000 pcs.ha^{-1}). The largest beech trees were recorded on the plot with 5,000 pcs.ha^{-1} (2 × 1 m) while the trees with the largest diameter were found on the plot with the initial density of transplants 2,500 pcs.ha^{-1} (4 × 1 m). Thanks to early canopy closure and self-cleaning, the best quality showed the beech planted on the 2 × 1 m plot.

In the Czech Republic, the Research Institute of Forest and Game Management in Opočno has been testing different planting densities of beech – 10,000 pcs.ha^{-1} (1.5 × 1.5 m) and 2,500 pcs.ha^{-1} (2×2 m). Bartoš and Souček (2010) summarized the hitherto results of this experiment after 14 years from its establishment as follows: "The effect of spacing and different competition starts to show on the stem quality and branchiness. Due to higher competition, beech plants spaced 1×1m have a higher proportion of high-quality individuals and a lower proportion of the poorest quality individuals. Differences in the stem quality are still not demonstrable in other spacing patterns. The influence of spacing shows in the character of branching; a higher share of small-diameter branches at 1 × 1 m and 1.15 × 1.15 m may show on the stem quality in the future. At this stage of development, however, beech plants growing at 1.5 × 1.5 m and 2 × 2 m cannot be considered of distinctly worse quality. The character of stem and crown quality will gradually change with the increasing stand age and mutual competition." The authors suppose, nevertheless, that their results will incline in the future rather to the opinions of Šindelář *et al.* (2004) who consider a severe reduction of transplants per hectare as illogical and not sufficiently substantiated.

This work aims at identifying the influence of different densities at planting European beech (5,000 pcs.ha^{-1}, 10,000 pcs.ha^{-1}, 15,000 pcs.ha^{-1} and 20,000 pcs.ha^{-1}) on the morphological quality of the above-ground part. A comparison was also made of the square and rectangular spacing pattern of transplants.

MATERIAL AND METHODS

The Stašov research facility with the experimental testing of the European beech spacing pattern is situated in Stand 263 B 11b in the forest district of Radiměř, Forest Administration in Svitavy, operated by Lesy České republiky, s.p. (Forests of the Czech Republic, State Enterprise). Site conditions are characterized by the forest type 5K7 – Acidic Fir-Beech with tufted hair grass and oxalis; primary management group 431 – spruce management on acidophilous sites of medium elevations. Predominant geological bedrock is quartz sandstone and feldspathic sandstone. Soil type is mesotrophic brown forest soil.

Total area of the facility is 2.17 ha and approximately a half was used for our research on beech. The original stand was felled in the winter period 2004/2005 and the plot was fenced. In the spring of 2006, we established a spacing pattern experiment in it with the planting stock of European beech from a best-quality local provenance. Two-year bare-rooted transplants were undercut (1–1) after the first year of growing. The initial height of their shoot part was 36–50 cm and the root collar diameter was 6 mm. Taller and larger-diameter transplants (above-ground part height 50–70 cm) were used only in plots 3a and 3b – see below. The method of planting was into holes sized 25 × 25 cm.

The experiment with the spacing pattern included four plots (each ca. 25 × 100 m) with different initial densities of transplants. Each of the plots was subdivided into halves sized ca. 25×50 m with a square spacing pattern on one part and rectangular spacing pattern on the other part (except for Plot 2 where only the square spacing patterns were monitored) (Tab. I).

The plots were surveyed in the years 2008, 2009 and 2011, i.e. after 3, 4 and 6 years from planting. With respect to the fact that we used 2-year transplants, the beech trees assessed were old 5, 6 and 8 years. No tending measures were applied on the plots, only protective measures.

The aim of our work was to ascertain the influence of the density of European beech transplants at planting on the morphological quality of the above-ground part of the plants. Studied parameters were as follows:

1. Height (cm), i.e. distance from the soil surface to the tip of the terminal bud;
2. Root collar diameter (mm), i.e. stem diameter at a height of 3 cm above the ground surface;
3. Stem form: normal (terminal shoot without branching; if other shoots occur, these must not be of a larger diameter than a half-diameter of the terminal shoot at the setting point); fork (terminal shoot forked into two of which none has a diameter lesser than a half-diameter of the other one at the point of forking); triple stem (terminal shoot branched into three shoots of which none has a diameter less than a half-diameter of the shoot with the largest diameter);
   The forking (branching) height of forks and triple stems (cm) was recorded in the year 2009.
4. Stem continuity; in 2008 and 2009, we recorded only a presence of the cylindrical (or non-cylindrical) stem, i.e. stems with a maximum warping up to ± 5 cm from its imaginary axis (or more); in 2011, each stem was assessed for a warping of up to 3 cm, 5 cm, 10 cm and more than 10 cm from the imaginary stem axis;
5. Diameter of branches: diameter of branches shooting from the stem was assessed in respect of stem diameter at the point of branching (numbers of branches were recorded reaching up to 25 % of stem diameter and up to 25–50 % of stem diameter);
6. Crown: setting height (distance from the soil surface to the first branch on the stem in cm), form (ovoidal, globular, cylindrical, obovate, one-sided crown);
7. Injury: biotic (namely by gall midge and/or by wildlife and mildews); abiotic (namely by frost); loss on transplants;
8. Colour of assimilatory organs (green plants and plants with deficiency symptoms on leaves).

In the third year after planting, we assessed each 5th beech plant in all rows. In the fourth year after planting, all individuals were assessed from each 4th row, and in the sixth year after planting, all individuals were assessed from each 6th row (200–400 beech trees on one plot), which provided for

I: *Experimental plots, initial densities and spacing of European beech transplants*

Plot	Density of transplants (pcs.ha^{-1})	Spacing
1a	5 000	1.4 × 1.4 m
1b		2 × 1 m
2a	10 000	1 × 1 m
2b		1 × 1 m
3a	15 000	0.8 × 0.8 m
3b		1 × 0.65 m
4a	20 000	0.7 × 0.7 m
4b		1 × 0.5 m

randomness of the choice. All data sets were assessed for the basic prerequisites of data (normality of division, independence of elements, homogeneity of choice and minimal sample size). Considering the large amount of the assessed beech trees, all these prerequisites were confirmed. Basic characteristics were calculated by using the descriptive statistics function of the Excel programme. The comparison of data sets was made by using parametric tests of the Statistica programme (multi-factorial and/or single-factor ANOVA). The level of significance (α) in all tests was 0.05 and vertical columns in the statistical charts indicate 95% reliability intervals.

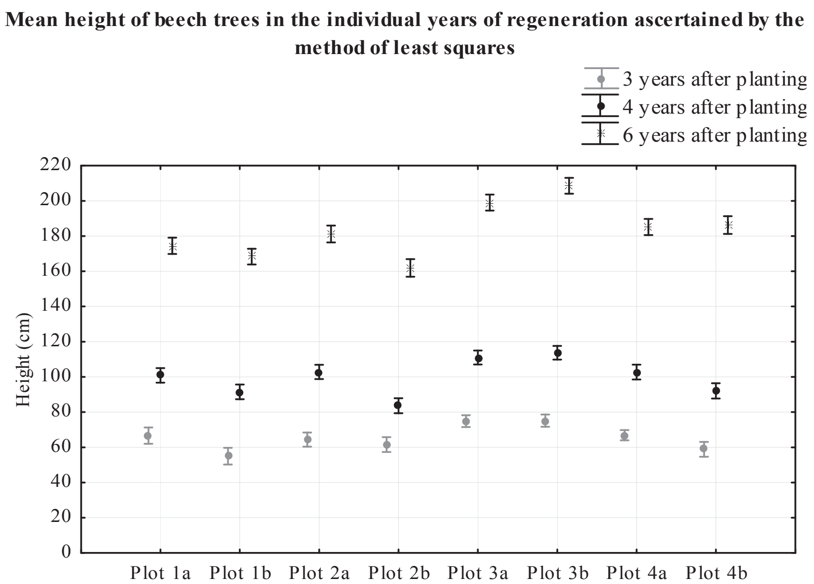
RESULTS

The loss on beech transplants three years after planting ranged from 4–9%; four years after planting, the loss was 5–16% and did not markedly increase any more. The injury by abiotic and biotic agents was negligible and comparable on all plots. A gall midge attack affected the entire experimental site six years after planting, which was however not severe enough to influence losses or the growth and development of the plantations. The lowest numbers of affected plants were found on Plots 1a and 1b with the lowest densities of transplants per hectare. In any case, the chosen density and spacing of beech had no essential influence on the loss of or damage to the young plantation. As compared to stands with enclosed canopies, more open stands have less favourable conditions for the development of insect pests.

Three years after planting, all plots showed only a small increment as compared with the initial height of the transplants (Tab. II), the reason being an after-planting shock. Comparing the height of beech trees on the individual plots (Fig. 1), we found statistically significant differences both between the respective years of survey and between the plots (at all times p = 0.0000). Tab. III shows the statistically significant differences between the plots. The differences between the plots apparently grew with the

II: *Mean height, diameter, root collar diameter and increment of European beech on the experimental plots in the individual years of regeneration*

Plot	Initial number of transplants (pcs.ha^{-1})	Spacing of transplants	Mean height (cm)			Mean increment (cm)		Mean root collar diameter (mm)		
			3 years after planting	4 years after planting	6 years after planting	4 years after planting	6 years after planting	3 years after planting	4 years after planting	6 years after planting
1a	**5 000**	**1.4 × 1.4 m**	66.6	100.9	174.5	34.3	42.8	11.0	15.30	26.4
1b	**5 000**	**2 × 1 m**	55.0	91.5	168.4	36.5	39.5	9.7	14.14	23.3
2a	**10 000**	**1 × 1 m**	64.4	102.8	181.2	38.4	40.3	12.0	16.42	26.4
2b	**10 000**	**1 × 1 m**	61.5	83.6	161.9	22.1	38.0	9.9	13.28	21.9
3a	**15 000**	**0.8 × 0.8 m**	74.8	111.0	199.0	36.2	46.8	11.0	14.29	24.0
3b	**15 000**	**1 × 0.65 m**	75.2	113.7	208.5	38.5	45.1	13.0	16.01	27.9
4a	**20 000**	**0.7 × 0.7 m**	66.9	102.8	185.2	35.9	40.9	11.8	15.45	23.9
4b	**20 000**	**1 × 0.5 m**	58.9	92.1	186.2	33.2	42.5	10.1	13.86	23.3



1: *Mean height of beech trees on the experimental plots in the individual years of regeneration*

III: *Homogeneous groups of the mean height of beech trees in the individual years of regeneration ascertained by HSD test with dissimilar amounts of elements in the sets (a group without statistically significant differences includes plots marked with asterisks in the given column)*

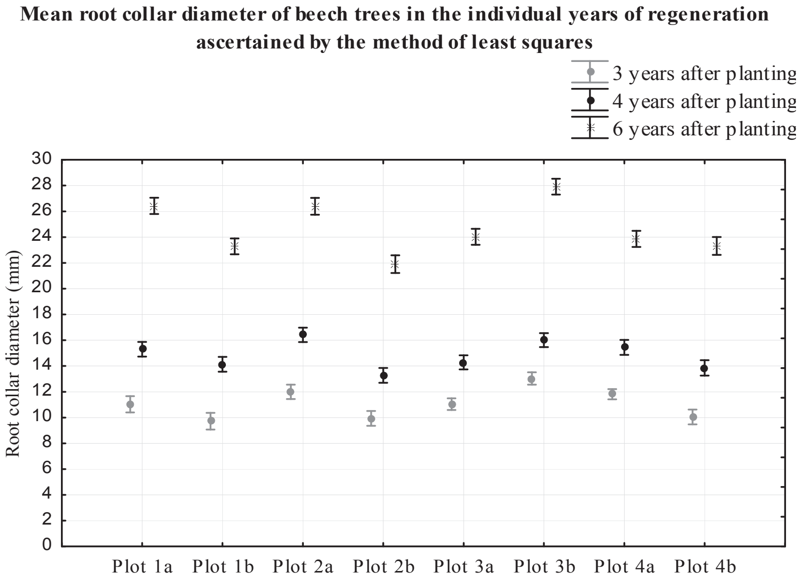
Plot	Mean height (cm)		Homogeneous groups of data without statistically significant differences												
			1	2	3	4	5	6	7	8	9	10	11	12	13
1b	55.0	3 years after planting	***												
4b	58.9		***												
2b	61.5		***												
2a	64.4		***	***											
1a	66.6		***	***	***										
4a	66.9		***	***	***										
3a	74.8			***	***	***									
3b	75.2				***	***									
2b	83.6	4 years after planting				***	***								
1b	91.5						***	***							
4b	92.1						***	***	***						
1a	100.9							***	***	***					
4a	102.8								***	***	***				
2a	102.8								***	***					
3a	111.0									***	***				
3b	113.7										***				
2b	161.9	6 years after planting										***			
1b	168.4											***			
1a	174.5											***	***		
2a	181.2												***		
4a	185.2												***		
4b	186.2												***	***	
3a	199.0													***	***
3b	208.5														***

increasing time. Higher values were clearly reached by beech plants on Plots 3a and 3b, which had been however established with larger-diameter and taller transplants that still keep on showing the highest increment. However, the height of transplants has not been affected by the spacing pattern (square or rectangular) or density up to now. Nevertheless, our results suggest that in the further development, the beech trees planted at higher densities could reach a greater height as compared with the lower-density spacing patterns (growing differences between the plots ranked according to an existing order from the least to the greatest mean height). This is in a good agreement with the known natural patterns where a higher canopy density would restrict the diameter growth and the trees would exhibit a faster height increment due to severe side competition.

If we compare the root collar diameter of beech trees growing on the individual plots, the data sets show statistically significant differences ($p = 0.0000$) between the individual years, too (Tab. II, Fig. 2). The tree-diameter differences were growing during the monitoring and six years after planting, markedly greater diameters were found on Plot 1a, 2a and 3b (Tab. IV). Thus, the influence of density and spacing on the stem diameter was not recorded. In general terms, however, trees growing at a lower density spacing pattern reached larger diameters as compared with a closed canopy since the competition of neighbouring individuals was not so severe and made possible the stem diameter growth as well as the spreading of branches. The diameter increases and reacts slower to the released space; this is apparently why the effect of density has not been demonstrated so far.

Three years after planting, Plot 4a exhibited a markedly lower number of beech trees with the continuous stem; this situation improved within a year, and four years after planting, all plots reached comparable values (79–88 %). Six years after planting, Plot 3b exhibited a distinctly higher number of individuals with a severe stem warping – nearly 80% (> 5cm from the stem axis). Other plots were comparable in this parameter – with a share of beech trees with a stem warping < 5 cm (ca. 50–60 %), which indicates that the influence of density and spacing on the stem continuous shape and warping does not show so far.

As to the stem form, branching and development of multiple-terminal plants, the plots did not exhibit any marked differences until four years from planting (Tab. V). Only Plots 3a and 3b exhibited



2: *Mean root collar diameter of beech trees on the experimental plots in the individual years of regeneration*

IV: *Homogeneous groups of the mean root collar diameter of beech trees in the individual years of regeneration, ascertained by the HSD test with dissimilar amounts of elements in the sets (a group without statistically significant differences includes plots marked with asterisks in the given column)*

Plot	Mean root collar diameter (mm)		Homogeneous groups of data without statistically significant differences									
			1	2	3	4	5	6	7	8	9	10
1b	9.7	3 years after planting	***									
2b	9.9		***									
4b	10.1		***									
1a	11.0		***	***								
3a	11.0		***	***								
4a	11.8			***	***							
2a	12.0			***	***							
3b	13.0				***	***						
2b	13.3	4 years after planting			***	***						
4b	13.9					***	***					
1b	14.1					***	***	***				
3a	14.3					***	***	***				
1a	15.3						***	***	***			
4a	15.4							***	***			
3b	16.0								***			
2a	16.4								***			
2b	21.9	6 years after planting								***		
1b	23.3									***	***	
4b	23.3									***	***	
4a	23.9										***	
3a	24.0										***	
2a	26.4											***
1a	26.4											***
3b	27.9											***

V: *Stem branching form and height on the experimental plots in the individual years of regeneration*

Plot	Initial amount of transplants	Spacing of transplants	Proportions of beech trees with various stem forms (%)														Mean height of stem branching (cm) into fork, triple stem, two forks or three forks
			3 years after planting				4 years after planting					6 years after planting					
	(pcs.ha^{-1})		Normal	Fork	Triple stem	Multiple stem	Normal	Fork	Triple stem	2x fork	3x fork	Normal	Fork	Triple stem	2x fork	3x fork	4 years after planting
1a	**5 000**	**1.4 × 1.4 m**	60	38	1	1	77	18	0	5	0	46	45	0	7	2	49.1
1b	**5 000**	**2 × 1 m**	67	30	2	1	82	17	0	2	0	37	50	2	9	2	41.8
2a	**10 000**	**1 × 1 m**	62	28	3	8	69	23	0	6	1	55	39	0	6	0	60.8
2b	**10 000**	**1 × 1 m**	50	47	3	0	73	21	1	4	0	57	35	0	8	0	47.5
3a	**15 000**	**0.8 × 0.8 m**	69	28	2	0	74	23	0	2	0	66	34	0	0	0	69.6
3b	**15 000**	**1 × 0.65 m**	48	49	1	2	72	22	0	5	1	69	31	0	0	0	69.7
4a	**20 000**	**0.7 × 0.7 m**	56	36	5	2	75	23	0	2	0	81	19	0	0	0	50.4
4b	**20 000**	**1 × 0.5 m**	63	32	3	1	70	23	0	6	0	73	27	0	0	0	53.8

stem forking and triple stems after 4 years from planting (at a greater height of approx. 70 cm, which resulted from the use of larger transplants in the reforestation). However, six years after planting (Tab. V), an increase of malformed individuals on the plots with the lower initial number of transplants was quite obvious. It shows that the higher is the density, the greater amount of beech trees with a "normal" stem, and the lower number of forks, triple stems or individuals with other malformations occurs. Individuals with the stems of the poorest quality (triple stem, two forks and three forks) occur on the plots with the initial density of 5,000 pcs.ha^{-1} and 10,000 pcs.ha^{-1}; in the case of higher-density plantations, their presence was not recorded at all. The influence of spacing pattern on the stem form was not demonstrated.

Six years after planting, the beech trees on the individual plots had a comparable height of the crown setting. A statistically significant difference ($p = 0.0000$) was found in Plot 3a where the first branches began to appear considerably higher on the stem (21 cm) than on the other plots (16–18 cm). However, this is given by using the transplants of larger height and diameter and corresponding morphological quality at planting. Another plot with a higher setting of beech crown was Plot 3b (18.6 cm), in which a statistically significant difference from the other plots was not demonstrated though. In spite of the fact that the effect of density and spacing on the crown setting height was not yet shown, our results suggest that a further development could lead to a lower setting of crowns on the stem in the case of lower-density plantations.

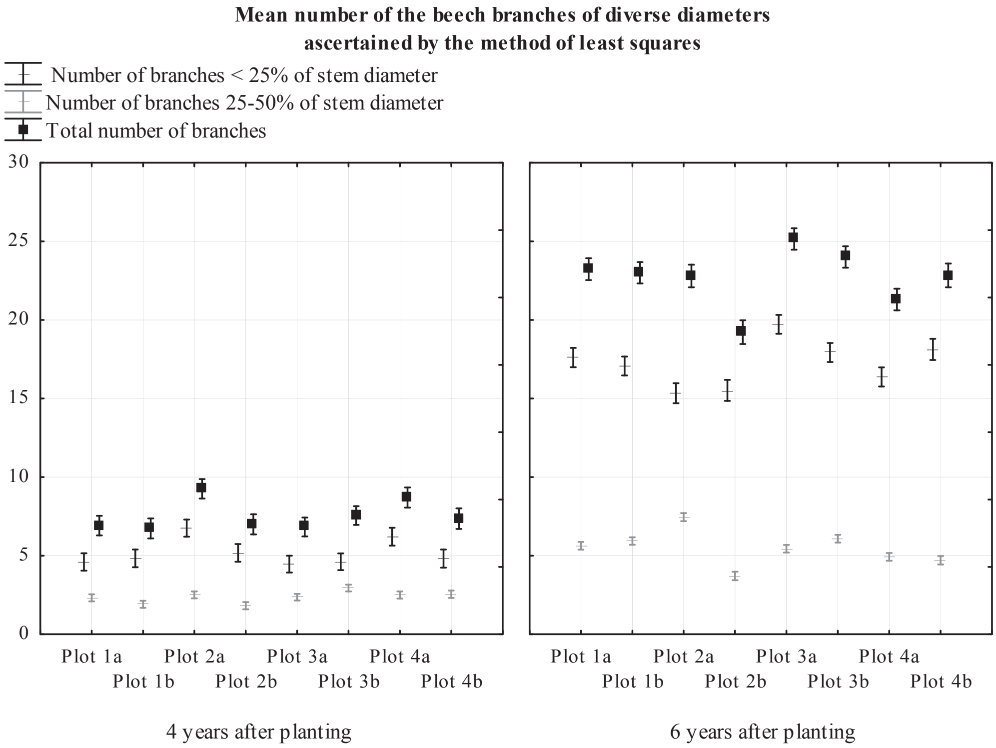
As far as the number of branches on the beech stems of different diameters is concerned, statistically significant differences were recorded between both the individual years (their number is increasing with time) and the individual experimental plots ($p = 0.0000$). Nevertheless, the results indicate (Fig. 3) that the abundance of larger- or smaller-diameter branches on the stems of beech trees or their total number had nothing to do with the plantation density or spacing up to 6 years after planting.

The crown form of the beech trees was assessed six years after planting (Fig. 4). It was obvious that Plots 3a, 3b, 4a and 4b (with closely spaced transplants) had a higher proportion of beech trees with cylindrical crowns (> 50% as compared with 20–30% in a more sparse spacing), which has to do with their gradual canopy closure and hence the restricted crown spreading. The unacceptable one-sided crown form appeared on the plots only exceptionally.

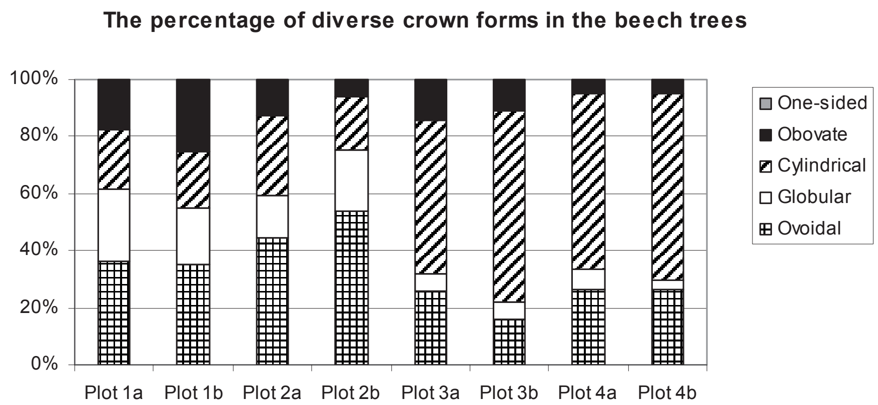
DISCUSSION

Results of our experiment with the spacing of European beech six years after planting suggest that none of the initial densities of transplants used (5,000 pcs.ha^{-1}, 10,000 pcs.ha^{-1}, 15,000 pcs.ha^{-1} and 20,000 pcs.ha^{-1}) can be claimed as absolutely inappropriate. The influence of the spacing arrangement itself (square × rectangular) did not show at all so far. References in literature indicate, too, that recommendations from similar experiments can be formulated only after a longer monitoring. For example, Bartoš and Souček (2010) did not arrive at clear conclusions even after 14 years of research. Botev *et al.* (1988–1995) specified more precisely the hectare numbers of beech transplants only after 13–16 years of research, and Muhle and Kappich (1979) after 15 years of research. Differences in experiments with the spacing of other tree species appear later as well; Páv (1985) described results of such trials with Scots pine plantations aged 11–16 years.

The hitherto results can be used to formulate at least partial conclusions now. The initial density of



3: *Mean number of the branches of diverse diameters on the individual plots 4 and 6 years after planting*



4: *The proportion of beech trees with diverse crown forms on the individual plots 6 years after planting*

beech transplants at planting affects the proportion of individuals with malformed stems. The higher is the density of the plantations, the fewer malformed individuals occur in them. Beech trees with stems of the poorest quality (triple stem, two forks and three forks) occurred only on the plots with the lower initial density of transplants (5,000 pcs.ha^{-1} and 10,000 pcs.ha^{-1}). Similarly, Bartoš and Souček (2010) observed the highest amount of the worst quality beech plants with the lowest initial density of the plantation. In spite of all this, we found 37% and 46% of promising good-quality individuals with the continuous stems on Plots 1a and 1b, respectively. This indicates that there is still a sufficient amount of promising beech trees (more than 1,800 pcs.ha^{-1}), which – if properly supported by tending measures – can form a high-quality stand. The comparison of measurements made 4 and 6 years after planting showed a conspicuous increase of malformed individuals whose amount may further change and the plots should be further monitored. It was generally demonstrated, however, that the height of stem branching is lower in the beech trees grown at wider spans between the transplants (Kantor *et al.*, 1975) and the quality of beech decreases (Leder and Weihs, 2000). Nevertheless, a larger distance between the transplants significantly affects the slenderness ratio, which characterizes the increased resistance of the young stand to wet snow threatening beech thickets and small pole stands at middle elevations in the autumn when the young trees still have not shed leaves (Mráček, 1989).

This is why we always have to take into account site conditions when considering the density of transplants. Šindelář *et al.* (2004) point out the existence of sites in which the beech is one of soil-improving and reinforcing tree species and hence can be planted at lower densities with its function being the same as in the main tree species, i.e. wood-producing function. This condition can be met only with a sufficient amount of transplants per hectare for a positive development of crowns and stems. Therefore, they consider this massive reduction of hectare amounts for the reinforcing and soil-improving tree species as illogical and insufficiently clarified. In any case, some authors point out (e.g. Heukamp, 1999; Kriegel, 2001) that good quality of the stand can be achieved only by using beech transplants of high genetic quality and a good stem form.

Differences between our experimental plots further grow in some morphological parameters and could reach undesirable level in the future. On the other hand, the beech plants originating from more advanced transplants clearly show the best growth habit even six years after planting. It follows therefore that should we need a plantation to grow rapidly and reach enclosed canopy as soon as possible, we can achieve this by using more advanced transplants (e.g. in localities inclined to rapid and severe weed infestation), which corresponds with the recommendations of Kantor *et al.* (1975), Kriegel (2001) etc.

The choice of the initial amount of beech transplants is affected by a number of other factors than only by the quality of the future stand. The most considered factors are the costs of site forestation (weed infested localities – higher amount; localities with massive snow cover – lower amount; possibility of complementing the young plantation with self-seeded trees from adjacent stands …). Nevertheless, first, we have to find an answer to the question what is the lowest limit for the hectare number of beech transplants in artificial forest regeneration to be able to achieve through tending a high-quality stand fulfilling its production function; only then we can consider the other factors. This is why it is necessary to continue in the monitoring of the experimental plots since the plantations are in the state before their first juvenile thinning, which will further influence the development of the individual plots. It is recommended to delimitate a part of the plot for a comparison without any measure.

CONCLUSIONS

The desired increase of the proportion of European beech in the forests of the Czech Republic will not do without the artificial introduction of the species into the stands that consist mostly of allochthonous spruce monocultures. Similarly as in other forest tree species, the artificial regeneration of beech features in the last several decades a gradual reduction of transplants per hectare aiming at the lowest possible forestation costs. What is a still acceptable limit of the initial density of young beech plantation, which would provide at felling age a high-quality beech stand with valuable timber assortments, is still not clear enough. Therefore, the aim of our work was to find out what is the influence of diverse numbers of beech transplants per hectare vat artificial forest regeneration (5,000 $pcs.ha^{-1}$, 10,000 $pcs.ha^{-1}$, 15,000 $pcs.ha^{-1}$ and 20,000 $pcs.ha^{-1}$) on the morphological quality of above-ground parts of beech trees. The square and rectangular spacing patterns were tested in the experimental variants with varying densities of transplants.

Conclusions from the hitherto results of our research are as follows:

1. The chosen density and spacing pattern had no essential influence on the loss or injury of trees after planting;
2. The planting of advanced transplants can speed up the plantation's canopy closure and its growing out from the adverse influence of weeds. Rapid growth at the simultaneous maintenance of better quality are obvious even six years after planting;
3. The higher is the density of the plantation, the fewer individuals with malformed stems occur in the plantation. The plots with the lowest density of transplants (5,000 $pcs.ha^{-1}$ and 10,000 $pcs.ha^{-1}$) with the least qualitative individuals (triple stem, 2 forks, 3 forks) still exhibit a sufficient amount of promising beech trees (more than 1,800 $pcs.ha^{-1}$); this is why this initial density of transplants cannot be considered as inappropriate.

Our experiment with the spacing of European beech did not determine any of the tested initial densities of transplants or spacing patterns as inappropriate even after six years from the establishment (planting). Nevertheless, the research results suggest that differences between the plots may further increase and the share of individuals with poor morphological characteristics could reach undesirable level with the time.

SUMMARY

Artificial forest regeneration has been dealing with a question of how many plants should be used per hectare of clear-cut area, which would ensure that the plants develop a stand of desired quality in the future and, at the same time that the costs spent on reforestation and other measures focused on stand protection and tending are as low as possible. In the Czech Republic, the initial numbers of European beech seedlings and transplants used in forest regeneration were decreasing since about the 1950s and reached the current by law stipulated minimum of 8,000–9,000 $pcs.ha^{-1}$ in beech as a main tree species, and 4,000–5,000 $pcs.ha^{-1}$ in beech used as a reinforcing and soil-improving tree species. The aim of our research was to identify the influence of the initial density of transplants at artificial regeneration of stands with the European beech. Tested variants were 5,000 pcs.ha^{-1}, 10,000 pcs.ha^{-1}, 15,000 pcs.ha^{-1} and 20,000 pcs.ha^{-1} and in a majority of them the square and rectangular spacing patterns were further compared. The evaluation was made 3, 4 and 6 years after planting in which 2-year old transplants were used of European beech of the best local provenance and quality. Measured parameters included the length of above-ground part of beech plants, root collar diameter, increment, stem continuity and warping, stem branching character and height, crown setting height and form, number and diameter of branches, injury to the plants and loss after planting. Our research results showed that the chosen density and spacing pattern had no essential influence on the loss of or injury to the trees after planting and that the canopy closure of the young plantation can be accelerated by planting more advanced transplants, which also supports fast growing out from the negative influence of weeds and leads to the maintenance of better quality of the plantation. Six years after planting, a majority of morphological parameters of beech did not show any differences between the variants with diverse densities of transplants or different spacing patterns. Nevertheless, our results clearly indicate that the higher is the density of the young plantation the fewer individuals with malformed stems occur on the plantation. Plots with the lowest density (5,000 pcs.ha^{-1} and 10,000 pcs.ha^{-1}) exhibited the occurrence of the poorest-quality individuals (triple stem, two forks and three forks); they however still contain a sufficient number of promising beech trees (more than 1,800 pcs.ha^{-1}). Therefore our experiment did not determine any of the tested initial densities of beech transplants or spacing patterns as inappropriate even after six years from the planting. Other authors deduce unambiguous final conclusions only after more than 10 years of research. It is therefore necessary to continue in the monitoring.

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