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Intensively fertilised seedlings of the beech (*Fagus sylvatica* L.) for artificial regeneration of the spruce stands in the process of conversion

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ABSTRACT: Artificial regeneration of autochthonous target tree species plays an important role in the process of conversion of forest stands. The European beech is one of the most suitable and most frequently used tree species in this process. Modern technologies of intensive methods of the cultivation of the European beech seedlings provide, among others, a possibility to increase the proportion of this tree species in reforestation more quickly. It is however necessary to test at what types of sites this planting material can be used. The health status and growth of intensively grown beech seedlings in the first years after planting were studied on 2 research plots. Proper intensive fertilisation of the beech seedlings affected positively both the initial height and growth. Even the slow-release fertiliser did not negatively influence the beech after planting. The health status of the beech is excellent after 4 years, the average height of plants with different fertilisation treatments having become equal. It is to conclude from the hitherto obtained results that a slow-release fertiliser in the substrate has a positive effect on the plant growth, and that different fertilisation variants did not cause any serious root deformations of the beech planting stock samples taken 4 years after planting. The impacts of prior nursery fertilisation upon the beech planted under the conditions of extreme sites are further investigated.

Keywords: European beech; fertilisation; containerised seedlings

The artificial regeneration of broadleaved tree species is the main way of increasing the proportion of autochthonous trees species in order to reduce extensive spruce monocultures. The European beech plays one of the most important roles on the European scale of conversions, and so it is appropriate to improve the methods and to enlarge the possibilities of its artificial regeneration. The beech is the most important commercial broadleaved tree species in the forest sector of the Czech Republic while its proportion in the forest artificial regeneration is gradually increasing. In the conditions of the Czech Republic, the use of containerised planting material of forest tree species has a long tradition (Dušek et al. 1985; Mauer 1997; Jurásek 2000), and modern technologies of intensive growing of this planting stock bring many advantages, e.g. a substantial shortening of the time of growing in a nursery. It is also possible to respond to the increasing demand for high-quality planting material of beech much more quickly. In the technology of growing the containerised planting material on the air layer, the growth of roots is interrupted on the boundary of the container and the air layer, which leads to a subsequent multiplication of fine roots inside the container. A compact root system is formed in this

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way that is disposed to grow well after planting onto permanent sites because the higher proportion of fine roots in this technology is a very positive feature from the aspect of plant survival (Nárovec 2003; Nárovcová 2003). The European beech is a tree species exploiting the intensive growth environment of nursery operations (Jurásek 2000). In the system of testing the biological safety of containers for the containerised planting material of the beech, 11 types of containers were recommended in the Czech Republic (Jurásek et al. 2006). The paper presents the results of the morphological parameters of the European beech four years after reforestation of sites of different types when beech seedlings were produced in three variants of fertilisation dose. One of the longer-term objectives of these experiments is to assess whether the intensive fertilisation of this planting material will have any negative effects on the growth and health states after the young trees have been planted into forest stands.

MATERIAL AND METHODS

An intensive nursery technology was used to grow one-year-old seedlings of the European beech. HIKO V 265 containers (cells 15 cm high, upper edge 4.8 cm long, density 368 cells per 1 m^2) were filled with the substrate at three levels of fertilisation using Osmocote (main nutrients – N 15%, P_2O_5 10%, K_2O 10%, MgO 3% including other microelements): treatment A – a recommended dose of the slow release fertiliser in the substrate (hereinafter "normal fertilisation into the substrate"), treatment B – luxury fertilisation of the substrate with a twofold dose of the slow-release fertiliser (hereinafter "luxury additional fertilisation of the substrate"), treatment C – the growth substrate was not fertilised, only foliar nutrition (Wuxal-super fertiliser in 0.2% strength contains: total nitrogen 8%, P_2O_5 8%, K_2O 6% including trace elements B, Fe, Cu, Mn, Mo and Zn) was applied during the growth season at a recommended dose (hereinafter "control – foliar nutrition only"). Fertilisers with different periods of nutrient release were applied within the framework of these main treatments (final substrate resulted from a thorough mixing of peat, inert bulk matter, and fertiliser); more detailed specification of these subtreatments is given in Table 1. The planting of one-year-old seedlings of the European beech onto the experimental plots was carried out in the autumn season, onto two experimental plots. The localities Trutnov (560 m above sea level, SLT 5K beech with fir on acidic site) and Zlaté hory (650 m a.s.l., SLT 5S beech with fir on nutrient-medium site) are climatically optimal for the European beech growth. Prior to planting, soil samples were taken from both localities to be analysed in a laboratory. The samples were analysed for pH (both H_2O and KCl), nitrogen (Kjeldahl), and plant-available nutrients (P, K, Ca, Mg). Neither extreme values nor nutrient deficiency was found in the soil samples. At least 500 trees were planted per treatment. Morphological parameters (height growth and root collar diameter) of these plantations and their health state were investigated every year. Ten samples of all variants were taken from both research plots in 2007. The samples were analysed in FGMRI laboratory in order to reveal root deformations in accordance to the valid standards of planting stock quality (ČSN 48 2215, 1998).

The data were statistically analysed using ANOVA for MS Excel and Bonferroni Multiple-Comparison Test (with control) which is a statistical tool in NCSS

Table 1. An overview of fertilisation treatments for growing one-year-old plantable seedlings of the European beech

Main treatments	Planting site	Treatments	Fertiliser used in nursery	Fertiliser dosage (kg/m^3)
Recommended dose of fertiliser in substrate	Trutnov, Zlaté hory	OS 12/4	Osmocote 12–14 months*	4
	Trutnov, Zlaté hory	OS 3/2	Osmocote 3–4 months	2
Luxury dose of fertiliser in substrate	Trutnov, Zlaté hory	OS 12/8	Osmocote 12–14 months	8
	Trutnov, Zlaté hory	OS 3/4	Osmocote 3–4 months	4
No fertiliser in substrate	Trutnov, Zlaté hory	Control	Foliar nutrition (Wuxal)	–

*The time of nutrient release declared by the manufacturer

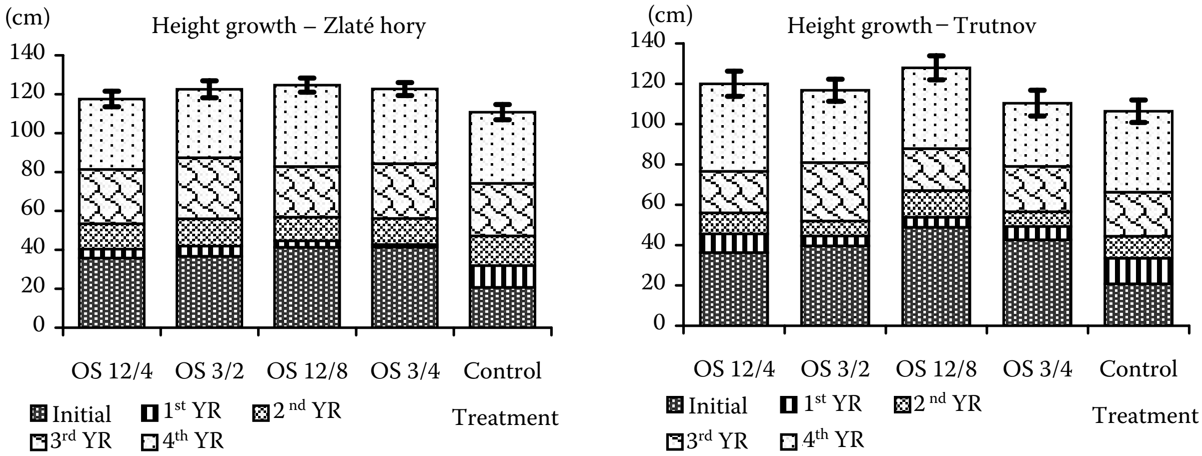

Fig. 1. The height growth of European beech plants with different fertilisation treatments on research plots Zlaté hory and Trutnov. For the description of treatments see Table 1. Vertical bars demonstrate intervals of confidence of total height

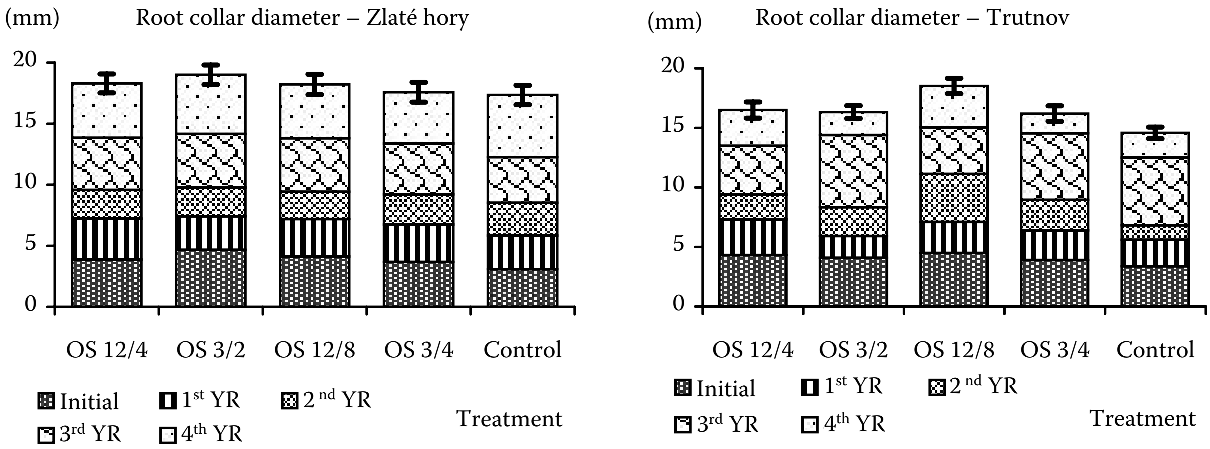

Fig. 2. Root collar diameter of European beech plants with different fertilisation treatments in the particular years after planting onto Zlaté hory and Trutnov research plots. For the description of treatments see Table 1. Vertical bars demonstrate intervals of confidence of total collar diameter

software. Error bars in Figs. 1 and 2 depict the confidence intervals ($P = 0.05$).

RESULTS AND DISCUSSION

The impact of the fertilisation treatments on the growth of the European beech was studied on 2 research plots under favourable growth conditions of beech natural range. It was a common feature for both research plots that the seedlings fertilised into the substrate had statistically significantly larger height and root collar diameter compared to the control with foliar nutrition (Table 2).

On the research plot Zlaté hory, a good health state had been observed since the establishment. The highest proportion of losses was due to the damage caused by murines, but total losses did not exceed 5%. In the first year after planting, relatively great differences between the treatments were found out in the damage or withering of terminal shoots of the planting material (Table 3). In the first year after reforestation, the lowest occurrence of such damage was recorded in the control treatment C (with foliar nutrition only), the highest in the treatments using the application of fertilisers with a shorter period of nutrient release. In the second year after planting, the occurrence of terminal shoots damage was minimal. It was the highest in the treatments where the slow-release fertiliser with a longer period of nutrient release had been applied. The presented results document the persistence of the effects of fertilisation in the nursery in the 1st and partly in the 2nd year after planting. Similarly, e.g. Williams and Hanks (1994) reported that large broadleaved seedlings grown with the application of high doses of fertilisers often had soft tissues and other unsuitable characteristics that could have adverse effects on their development after planting. The need of

Fig. 3. 4-year-old individuals from Zlaté hory research plot. Left – root system developed under conditions of luxury Osmocote dose, right – control

Table 2. Morphological features of the subtreatments of the European beech seedlings before planting to regeneration experimental plots. The description of treatments see in Table 1. In the columns, the values followed by different letters are significantly different (P = 0.05)

Treatment		Height (cm)	Root collar diameter (mm)	Root/above ground dry matter ratio	Root deformation (%)
	x	**38.6b**	**4.7bc**	**99.0c**	0
OS 12/4	*Sx*	9.52	0.74	0.30	
	n	100	100	100	
	x	**43.7c**	**5.0bc**	**96.6c**	1
OS 3/2	*Sx*	11.21	0.86	0.31	
	n	100	100	100	
	x	**44.4c**	**4.6b**	**79.3b**	1
OS 12/8	*Sx*	11.94	0.79	0.28	
	n	100	100	100	
	x	**45.4c**	**5.0c**	**62.3a**	1
OS 3/4	*Sx*	10.27	0.81	0.23	
	n	100	100	100	
	x	**19.7a**	**3.8a**	**160.6d**	0
Control	*Sx*	3.16	0.49	0.61	
	n	100	100	100	

Table 3. Percentage of damage occurrence of terminal shoots during 1st and 2nd years after outplanting on the plot Zlaté hory. The description of treatments see in Table 1

Treatment	Damage frequency	
	1st year (%)	2nd year (%)
OS 12/4	9.7	1.4
OS 3/2	16.3	0.5
OS 12/8	11.0	2.2
OS 3/4	14.2	0.2
Control	3.1	0.2

balanced nutrition for a good survival and resistance was accentuated by Barnes (1994), Aldhous and Mason (1994), Grassi (1996), Prasad (1996), and Libus (2006). Mauer and Palátová (2004) also pointed to the risk of the root deformations as a result of inappropriate fertilisation.

The highest relative increment in two years after planting occurred in the control treatment. The height growth (Fig. 1) of this treatment was positively influenced by the lower occurrence of withered terminal shoots that were more frequent in the treatments using fertilisation into the substrate. After four years of growth the height differences between the treatments applying the slow-release fertiliser and the control (foliar nutrition) were gradually equalised on both plots even though they have remained statistically highly significant until now (except Trutnov OS 3/4 and Control). Four years after planting the control variant was statistically different from the fertilised variants OS 12/4, OS 3/2 and OS 2/8. This is an indirect proof that the slow-release fertiliser had been already consumed and the roots should spread freely outside the root ball. An important finding is that four years after planting the beech plants of all treatment variants including the control satisfy the criteria of an established plantation.

At the time of planting, i.e. after growing in the nursery, the planting material with the application of a slow-release fertiliser into the substrate had significantly larger root collar diameter compared to the control, i.e. to the plants that had received only foliar nutrition in the nursery. The evaluation of the diameter increments in the planting experiments is shown in Fig. 2. No significant differences occurred in the collar diameter on the plot Zlaté hory (Table 4). On the plot Trutnov, the collar diameters in the variants of fertilisation treatment OS 12/4, OS 3/2, and OS 12/8 differ significantly from the control.

Table 4. Above-ground height, root collar diameter, and number of root deformations in the variants of fertilised beech planting stock in 4th year after planting on both plots Zlaté hory and Trutnov. In the columns, the values followed by different letters are significantly different ($P = 0.05$)

Locality		Zlaté hory			Trutnov		
Treatment		height (cm)	root collar diameter (mm)	root deformation (%)	height (cm)	root collar diameter (mm)	root deformation (%)
OS 12/4	*x*	**117.50ab**	**18.30a**		**119.90ab**	**16.60b**	
	Sx	35.24	4.38		31.93	3.48	
	n	298.00	123.00	0	101.00	101.00	1
OS 3/2	*x*	**124.70b**	**19.00a**		**117.70ab**	**16.50b**	
	Sx	38.92	4.61		28.77	2.95	
	n	309.00	128.00	2	100.00	100.00	0
OS 12/8	*x*	**122.50b**	**18.20a**		**128.00b**	**18.60b**	
	Sx	34.96	4.57		30.24	3.40	
	n	359.00	116.00	1	100.00	100.00	2
OS 3/4	*x*	**122.70b**	**17.60a**		**110.40a**	**16.20ab**	
	Sx	35.40	4.67		32.49	3.29	
	n	432.00	128.00	2	100.00	100.00	0
Control	*x*	**110.80a**	**17.30a**		**107.40a**	**14.80a**	
	Sx	38.28	4.19		29.72	2.80	
	n	370.00	106.00	4	100.00	100.00	0

Different-dose Osmocote fertilisation did not result in significantly increased number of root deformations (8 occurrences) compared to foliar nutrition control (4 occurrences). Moreover, no serious deformation affecting the stability of the beech plants was found (Fig. 3). To verify the further development, the analysis of the root samples will be repeated in the next years.

CONCLUSIONS

The results of the investigation of the intensively grown planting stock of the beech with different fertilisation treatments, growing under relatively optimum conditions, document that:

– only minimum losses were recorded (max. 5%) with all experimental treatments,
– the intensively fertilised greenhouse planting stock (plugs) can be used for artificial regeneration of plots with favourable growth condition without negative impacts on its survival and growth in the first years after planting,
– in spite of marked morphological differences between the plants fertilised into the substrate and those of the control treatment (application of foliar nutrition only), they all achieved the parameters of established plantation in the same time interval (in 4th year after planting),
– the equalisation of average heights of the beech plants that obtained different fertilisation treatments indicates that the slow-release fertiliser has been already consumed and the roots can spread freely outside the root ball,
– different variants of fertilisation did not cause any serious root deformations of the beech planting stock samples taken in 4th year after planting, therefore the stability of plantation is not threatened. Neither the substrate-fertilised stock nor the foliar-fertilised one differed in terms of the root deformation frequency.

In other parallel experiments, the impact of intensive nursery fertilisation on the establishment of beech plantations in extreme growth conditions is studied. The results will be known in the next years.

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Využití intenzivně hnojeného sadebního materiálu buku lesního při přeměnách smrkových monokultur

ABSTRAKT: Umělá obnova původních cílových druhů dřevin má důležitou úlohu v procesu přeměny lesních porostů. Jednou z nejdůležitějších a nejčastěji používaných dřevin v tomto procesu je buk lesní. Moderní technologie intenzivních postupů pěstování krytokořenného sadebního materiálu buku lesního přinášejí mimo jiné možnost rychlejšího zvyšování podílu této dřeviny při umělé obnově lesa. Je ale třeba ověřit, na jakých typech stanovišť je možné tento sadební materiál použít. Zdravotní stav a růst intenzivně pěstovaného sadebního materiálu buku v prvních letech po výsadbě byl sledován na dvou lokalitách s relativně optimálními růstovými podmínkami. Vyvážené intenzivní hnojení semenáčků buku lesního ve školce pozitivně ovlivnilo jejich velikost v době výsadby i následný růst. V podmínkách příznivých pro růst buku nemělo intenzivní hnojení dlouhodobější negativní účinky na odolnost k nepříznivým klimatickým vlivům, působícím po výsadbě, a to ani v případě použití hnojiv s dlouhou dobou uvolňování živin. Buk vykazuje po čtyřech letech růstu výborný zdravotní stav a na relativně příznivém stanovišti pro buk došlo téměř k vyrovnání průměrné výšky rostlin u různě hnojených variant. Ze získaných výsledků vyplývá, že pěstování sadebního materiálu buku s přidáváním pomalu rozpustných hnojiv do substrátu má pozitivní vliv na růst. Různý způsob hnojení krytokořenných semenáčků buku ve školce neměl negativní efekt na tvorbu závažných kořenových deformací kořenového systému čtyři roky po výsadbě. Možné dopady použití různých způsobů hnojení ve školce na růst sadebního materiálu buku na extrémnějších stanovištích jsou v současnosti předmětem výzkumu.

Klíčová slova: buk lesní; hnojení; krytokořenný sadební materiál

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