Possibilities of using rooted cuttings of European beech (*Fagus sylvatica* L.) for stabilisation of forest ecosystems

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ABSTRACT: Vegetative propagation of forest tree species is of great importance not only for breeding programmes but also for the conservation of valuable populations of tree species. Important is also a possibility of improving the genetic quality of established stands. Beech is a tree species that can substantially increase the stability of forest ecosystems. Minimal information is available about the ontogenesis of rooted cuttings of beech in forest stands for the time being. In our experiments that were gradually established since 1993 we acquired the first significant results of the evaluation of health status, phenological phenomena and growth of these plants. Our findings indicate that it is possible to use rooted cuttings as an element stabilising man-made forest stands including the transferred genetic quality. The evaluation of the 2nd generation rooted cuttings of beech also provided positive results.

Keywords: beech; rooted cuttings; plantings; ecosystem stabilisation

Autovegetative techniques of forest tree species propagation will be used on a larger scale in future. These methods may also contribute to the fast reproduction of valuable populations of tree species while their genetic identity is guaranteed, and may be a full-value substitute source for forest reproduction when a sufficient quantity of good-quality seed is not available Jurásek et al. (1997). Important is also a possibility of clone selection in relation to the anthropogenic load of forest stands and to potential climate changes. The plants produced by vegetative propagation may markedly increase the stability of forest ecosystems.

In connection with vegetative methods of propagation a risk of narrowing the genetic variability of a population created in a long-term evolutionary process is often mentioned. As shown by foreign experience, this problem can be solved even though relatively high quantities of rooted cuttings are produced (Kleinschmit 1989).

The technique of cuttings is applicable from breeding aspects, and it is used for the reproduction of valuable populations of tree species (Chalupa 1987; Šindelář 1987). Work with individual clones is necessarily connected with autovegetative propagation, which brings about some risks. First of all, it is a risk of narrowing the genetic spectrum of a species created by evolution, which may disturb the capacity of natural autoregulation. The artificial synthetic populations of forest tree species created by autovegetative methods must have a sufficient, genetically conditioned variability. To achieve this aim in practice a sufficient quantity of clones should be represented in a synthetic population at their appropriate percentage proportion (Šindelář 1987).

Literary sources dealing with the technique of beech propagation by cuttings are relatively scarce, especially foreign literary information from the present time is missing. An apparent reason why considerably smaller attention is paid to methods of autovegetative propagation in this species is that it is difficult to finish the production of rooted cuttings (Cornu et al. 1977; Spethmann 1982a,b; Schachler et al. 1987). Therefore the propagation of European beech by cuttings has not been used in forest operations until now. Factually all available literary sources dealing with the propagation of European beech (*Fagus sylvatica* L.) by cuttings were published

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only by specialists from Europe. U.S. literary sources provide information only on the rooting of cuttings of American beech *Fagus grandifolia* Ehrh. (Barnes 2003; Simpson 2005). In their papers elementary problems of rooting were solved, such as collection of cuttings, use of stimulators, microclimate of propagation facilities, etc. In the framework of our research we successfully produced rooted cuttings of beech in a nursery in the last years, which subsequently enabled us to carry out longer-term tests of growth of larger populations of these plants during forest reproduction (Jurásek 1990a,b).

The absence of specific literary information is perceivable in the segment of examining the growth of rooted cuttings of beech after they were planted onto permanent forest sites. Data on the growth of rooted cuttings of beech five years after planting compared to even-aged seedlings of generative origin were reported by Mauer and Palátová (1996). The results of a single observation of the development of European beech plantation did not document a significant difference to disadvantage of rooted cuttings. The rooted cuttings produced integral plants that have good capacities for further development and for the provision of all functions of beech stands like plants of generative origin.

The lack of good-quality beech seed is a crucial problem connected with an increase in the proportion of broadleaved species in forest reproduction. For these reasons it is necessary to test in greater detail a possibility of using rooted cuttings of beech for forest ecosystem reproduction. The need for high-quality planting material of broadleaved species is urgent in connection with the present trend of using stronger plants at lower per-hectare numbers, hence with a limited possibility of discarding low-grade and genetically unsuitable individuals in the course of silvicultural operations. In the framework of research in progress we have a sufficient quantity of rooted cuttings of beech (*Fagus sylvatica* L.) at disposal that were set out in forest stands. These plantations are unique by their area and quality not only in the CR but also in Europe. So in the course of research there is a unique opportunity for testing the usability of these plants for forest reproduction and improvement in forest ecosystem stability.

MATERIAL AND METHODS

The quality of rooted cuttings for planting was evaluated according to the standards of quality for plantable material, laid down by the Czech Technical Standard (ČSN 48 2115).

Plantable rooted cuttings of beech were set out onto permanent research plots (PRP) in the Krušné hory Mts., Jizerské hory Mts., in the area of Krkonoše Mts. and in the Trutnov area. On some PRP it was possible to compare the growth of rooted cuttings of beech with the planting material of beech of generative origin. As the size of plantations is very large, in this paper we present some data from PRP in the Trutnov area at an altitude of ca. 500 m above sea level, where the most extensive experiments were established. The findings from other areas where research is conducted according to the same methodology are factually similar.

Adaptability to the forest environment, especially health status and phenological phenomena, were examined in rooted cuttings of beech planted into forest stands. We also investigated the influence of different levels of nutrition in a nursery on survival, growth and health status of rooted cuttings after planting. Leaf samples were taken during the growing season for chemical analyses of the contents of basic elements. The growth parameters of rooted cuttings of beech were measured at the end of growing season only on representative samples of growing individuals. Considering the value of this planting material, destructive analyses for evaluation of the quality of root systems besides that of the aboveground parts are envisaged to be done in the years to come.

The results of biometric data measurements were processed by common mathematical and statistical methods; *t*-test and other statistical tests were used to determine significance of differences. In graphical representation significance of differences was expressed by intervals of reliability. Potential differences in the numbers of evaluated individuals in experimental variants in the particular years resulted from a need to discard from the evaluation plants with greater damage to aboveground parts caused by game or rodents.

RESULTS

No higher losses were observed in rooted cuttings of beech after their planting onto PRP. The mortality rate of rooted cuttings did not factually exceed 4% on all experimental plots in two years after planting. Such a good survival of rooted cuttings on regeneration areas was achieved after the planting of older, i.e. 3–4 years old individuals.

The observations of our experimental plantations of rooted cuttings of beech show better growth of stronger planting material until the phase of large-sized plants. It was confirmed e.g. by data on the

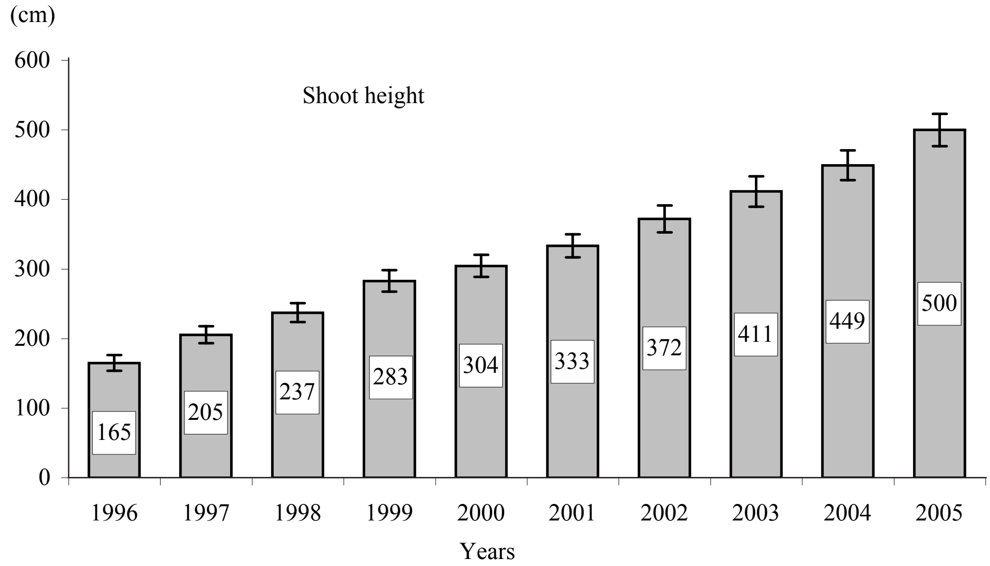

Fig. 1. Growth of older plantings of rooted cuttings of beech on Trutnov 2 PRP (use of large-sized plants – planting in 1993). Bars designate the intervals of reliability on a 5% significance level. If they do not overlap, differences are statistically significant

growth of rooted cuttings on Trutnov 2 PRP represented in Fig. 1 and in Table 1. In 2005 the aboveground parts of these plants reached the height of ca. 5 m. In these beech plants no greater deviations in phenological phenomena and health status were observed compared to the plantations of beech of generative origin.

The aim of another separate experiment conducted on regeneration PRP was to test the influence of different levels of nutrition in a nursery on subsequent health status and growth of rooted cuttings after planting. We used rooted cuttings at 2.5 years of age (growing formula according to the standard: plug 1.5 + 1) produced in a nursery in experiments with different levels of nutrition. In 1999 about 2,500 rooted cuttings from these experiments were planted onto Trutnov PRP. Two-year beech plants (growing formula: 1 + 1) of generative origin that had been grown as control plants in the nursery were used as the control.

Rooted cuttings and beech plants were not additionally fertilised during planting or further growth.

Table 2 shows the percentage of losses in experimental treatments in the first year after planting. The evaluation indicates that losses after planting were minimal in the rooted cuttings similarly like in the control plants of generative origin. Table 2 also shows contents of basic elements in leaves of rooted cuttings from different fertilisation treatments in the nursery. Differences between the treatments are minimal. Neither growth abnormalities nor differences in external morphological traits and phenological phenomena were observed in rooted

Table 1. Diameter growth of large-sized plants of beech (plug 1.5 + 2 + 1) on Trutnov 2 PRP (planting in 1993, n = 95)

	Breast-height diameter $d_{1.3}$ (mm)						
	1999	2000	2001	2002	2003	2004	2005
$\bar{x}$	19.00	21.90	26.50	32.30	36.50	40.40	47.20
$s_{\bar{x}}$	8.44	9.62	11.79	13.79	14.72	15.49	17.64

Table 2. Nutrient contents in the leaves of rooted cuttings and plants of beech and evaluation of losses on Trutnov 5 PRP a year after planting – 1999 (description of the variants see Table 3)

Treatment	Nutrient content (%)					Losses (%)
	N	P	K	Ca	Mg	
1	1.63	0.23	0.36	1.09	0.103	2
2	1.72	0.37	0.44	0.85	0.094	1
3	1.52	0.33	0.40	0.48	0.089	2

Table 3. Growth of rooted cuttings and plants of beech on Trutnov 5 PRP

Variant		Total height of shoots (cm)					Root collar diameter (mm)				
		1999	2000	2001	2003	2005	1999	2000	2001	2003	2005
1	$\bar{x}$	**26.0** *a*	**37.6** *a*	**63.1** *a*	**101.5** *a*	**148.9** *ab*	**6.4** *a*	**9.2** *a*	**12.3** *a*	**20.2** *a*	**27.3** *a*
	$s_{\bar{x}}$	8.20	12.34	25.32	41.03	53.7	1.61	2.38	2.30	5.47	7.95
2	$\bar{x}$	**27.2** *a*	**38.9** *a*	**59.8** *a*	**98.8** *b*	**149.2** *a*	**6.6** *a*	**8.6** *a*	**11.8** *a*	**18.8** *ab*	**26.5** *a*
	$s_{\bar{x}}$	8.96	12.12	21.82	37.64	45.29	1.82	2.03	3.14	6.19	7.82
3	$\bar{x}$	**22.9** *b*	**35.1** *b*	**53.1** *b*	**90.5** *b*	**135.5** *b*	**4.9** *b*	**7.0** *b*	**10.2** *b*	**17.4** *b*	**22.1** *b*
	$s_{\bar{x}}$	8.48	12.58	21.19	36.33	46.38	1.65	2.05	3.02	5.87	7.60

In comparison of two values in the column of values the same letters designate statistically insignificant differences on a 5% significance level
Description of variants:
1 – control, beech plants of generative origin, two years of age at the time of planting (growing formula in accordance with the standard ČSN 48 2115: 1 + 1)
2 – rooted cuttings of beech with intensive application of a liquid fertiliser Kristalon during growing in the nursery, 2.5 years of age at the time of planting (plug 1.5 + 1)
3 – rooted cuttings of beech grown in the nursery at a lower intensity of application of a solid fertiliser Silvamix, 2.5 years of age at the time of planting (plug 1.5 + 1)

cuttings in comparison with the individuals of generative origin.

Table 3 documents the growth parameters of variants of planting experiment. Data in the table show very good growth of all variants – it was comparable with control plants of generative origin. The individuals of generative origin (var. 1) had higher increments of shoots and stem diameter, but the differences were below the statistical significance level if they were compared with the variant of rooted cuttings that received a higher level of nutrition in the nursery (var. 2). Differences in growth were significant only if the plantations of generative origin (var. 1) were compared with rooted cuttings that had been additionally fertilised during their previous growing in the nursery with a low level of nutrition (var. 3). The positive effect of the previous high level of nutrition in the nursery on the growth of rooted cuttings several years after planting into a forest stand was evident from the comparison of variant 2 and 3, i.e. rooted cuttings with different levels of nutrition in the nursery. In the majority of the years of observation differences were significant in favour of rooted cuttings with higher nutrient supply (var. 2).

Table 4. Growth of 1st and 2nd generation rooted cuttings of beech compared to the planting material of generative origin

Variant		Total height of shoots (cm)						
		1998	1999	2000	2001	2002	2003	2005
A	$\bar{x}$	**73.0** *a*	**92.1** *a*	**121.1** *a*	**157.3** *a*	**208.5** *a*	**242.5** *a*	**333.9** *a*
	$s_{\bar{x}}$	31.25	39.54	44.66	51.00	68.91	66.26	77.9
	n	181	182	183	183	183	181	142
B	$\bar{x}$	**70.6** *a*	**90.4** *a*	**115.7** *a*	**142.5** *b*	**177.5** *b*	**212.8** *b*	**292.5** *c*
	$s_{\bar{x}}$	34.24	41.49	46.76	50.82	58.92	62.79	64.62
	n	97	96	97	96	95	94	65
C	$\bar{x}$	**81.0** *a*	**111.9** *b*	**151.0** *b*	**213.5** *c*	**266.8** *c*	**318.7** *c*	**385.6** *c*
	$s_{\bar{x}}$	20.21	32.27	36.59	53.34	58.80	79.08	74.54
	n	48	48	49	48	47	48	48

In comparison of two values in the column of values the same letters designate statistically insignificant differences at a 5% significance level
Description of variants:
A – rooted cuttings from a vegetatively established mother plantation (2nd generation of rooted cuttings)
B – rooted cuttings from a generatively established mother plantation (1st generation of rooted cuttings)
C – plants of generative origin – control

Interesting results were obtained in another planting experiment that was aimed at the examination of the growth of rooted cuttings of beech originating from conventional generative mother plantations (1st generation rooted cuttings) and of rooted cuttings from vegetative mother plantations (2nd generation rooted cuttings). Containerised rooted cuttings at 3.5 years of age (growing formula: plug 1.5 + 1 + lc) in biodegradable jute bags of 1 l in volume were used for planting on Trutnov 3 PRP in 1995. Beech plants of generative origin, of comparable age, were used as controls. In this experiment we did not find out any significant differences in survival and health status of rooted cuttings compared to the individuals of generative origin.

Table 4 shows the growth parameters of these rooted cuttings compared to beech plants of generative origin over a six-year period. Data document that the growth of planting material of generative origin (var. A) was more intensive than in rooted cuttings (var. B and C) (most differences are statistically significant). Even though the increments of rooted cuttings were found to be lower than in the plants of generative origin, the growth characteristics of the 1st and 2nd generation rooted cuttings (i.e. of those originating from cuttings of generative and vegetative mother plantation) were very good. The growth dynamics of rooted cuttings indicates that the lower increments of rooted cuttings, compared to the generative plantation, were not of substantial character and varied in the course of the years of observations. Higher increments of individuals originating from the 2nd generation mother plantation (var. A) compared to the rooted cuttings from the generative mother plantation (var. B) were very interesting findings. Differences in the height of shoots were statistically highly significant.

DISCUSSION

The findings about the autovegetative propagation of beech by cuttings published in literary sources with which we can confront the results of our experiments are scarce. Relatively most information is available on the first phases of this method, i.e. the rooting of cuttings, less information is about the problematic segment of the wintering of cuttings that have taken roots. More detailed information on the production of rooted cuttings and their growth in forest stands is factually missing in foreign literature.

In spite of partial success Radosta (1990) estimated the number of successfully produced rooted cuttings of beech to be hundreds of individuals. No information from foreign literary sources is available. Larger sets of rooted cuttings of beech (thousands of individuals) were produced in our experiments aimed at the optimisation of growing the rooted cuttings of beech (Jurásek 2002).

Our long-term experiments show that an optimum morphological quality of rooted cuttings grown in the nursery for plantings can be derived backwards from their survival and growth on regeneration plots. These results document (Jurásek 2000, 2001) that in rooted cuttings of beech due to their slower growth it is difficult to achieve parameters suitable for planting during two years of growing in the nursery. The experiments show that at this age the rooted cutting is not yet fully capable of being planted onto permanent sites (losses up to 50%, low growth dynamics for several subsequent years). On the contrary, the results presented in this paper illustrate the very good growth ability of plantations of older rooted cuttings of beech at the age of 3 years and more. Their health status and growth were found to be very good. The need of optimum nutrition of rooted cuttings in the nursery was confirmed so that the rooted cutting of beech would be physiologically well endowed for growth in the forest environment. These findings of ours concerning the good growth of rooted cuttings of beech comparable with the beech planting material of generative origin agree with the results of Mauer and Palátová (1996), who reported on the basis of an investigation, conducted in 5 years after planting, and aimed at the development of European beech plantation that was established by rooted cuttings and even-aged seedlings of generative origin that in none of the studied parameters (development of shoots and root system) was there a significant difference to disadvantage of rooted cuttings. The authors also stated that the rooted cuttings of beech formed integral plants that had at least so good capacities for good development and provision of all functions of beech stands as the plants of generative origin.

The good physiological condition of rooted cuttings of beech comparable with the planting material of generative origin was also proved by tests of tree species resistance to ozone effects (Günthardt-Goerg et al. 1999). The experiments did not factually show any differences in the resistance of rooted cuttings and seedlings to an ozone stress.

The hitherto positive findings about the growth of rooted cuttings of beech in forest stands may be confronted with the information acquired in another deep-rooted tree species, in sessile oak. In this tree species (Mauer et al. 2003) no substantial differences were reported in the size and growth dynamics of the aboveground parts of trees of generative and vegetative origin, their vitality and losses after planting. Based on the available knowledge of the growth of rooted cuttings of beech planted onto permanent forest sites it can be concluded that no greater problems were identified that would impede their use for forest reproduction.

CONCLUSIONS

The experiments testing the survival, health status and growth of rooted cuttings of beech in the course of forest reproduction provided these findings:

– Test experiments proved the usability of rooted cuttings of beech for planting in the forest. It is recommended to use the planting material (rooted cuttings) grown in a nursery in a three- to four-year growing cycle when the technology of transplanting to a larger container (1 l in volume) or lining out is used. The losses after planting did not exceed 10%.
– In outdoor plantings very good survival and growth of large-sized plants of beech, i.e. planting material of larger dimensions, were also proved.
– Survival, growth, phenological phenomena and health status of the plantations of rooted cuttings of beech, established gradually since 1992 and situated in different on-site conditions, are comparable with these characteristics in the planting material of generative origin.
– We demonstrated good growth dynamics in the first and second generation rooted cuttings of beech, i.e. in the individuals originating from cuttings collected from trees of generative and vegetative origin (plants and rooted cuttings of beech). It confirmed a possibility of using vegetative propagation in beech in repeated cycles.
– Beech plants produced by the technique of cuttings can be used for planting in forest stands. The vegetative method of propagation allows to conserve valuable populations and clones of this tree species. Relatively simple transfer and conservation of high genetic quality make it possible to use rooted cuttings of beech not only for an increase in forest stand biodiversity but also for an improvement in forest system stability.

References

BARNES H.W., 2003. Rooting potential of *Fagus grandifolia* cuttings. In: Combined Proceedings. International Plant Propagators' Society, Vol. *53*: 575–576.

CORNU C. et al., 1977. Recherche des meilleures conditions d'enrancinement des boutures herbacées de chêne rouvre (*Quercus petraea* /M./ Liebl.) et hêtre (*Fagus silvatica* L.). Annales des Sciences Forestières, *34*: 1–16.

ČSN 48 2115, 1998. Sadební materiál lesních dřevin. JURÁSEK A. et al., LOKVENC T., MAUER O. Praha, Český normalizační institut: 17.

ČSN 48 2115, 2002. Změna Z1. Sadební materiál lesních dřevin. JURÁSEK A. et al., MAUER O. Praha, Český normalizační institut: 16.

GÜNTHARDT-GOERG M.S. et al., 1999. Responses of young trees (five species in a chamber exposure) to near-ambient ozone concentrations. Water, Air, and Soil Pollution, *116*: 323–332.

CHALUPA V., 1987: Vegetativní rozmnožování listnatých dřevin řízky a metodou *in vitro*. Lesnictví, *33*: 501–510.

JURÁSEK A., 1990a. Využití autovegetativního množení smrku a buku řízkováním při záchraně genofondu. In: Úkoly semenářství a šlechtění při obhospodařování lesů v imisních oblastech. Sborník referátů z konference ČSAZ. Špindlerův Mlýn, Československá akademie zemědělská: 157–160.

JURÁSEK A., 1990b. K některým aspektům autovegetativního množení buku řízkováním. Lesnictví, *36*: 605–616.

JURÁSEK A., 2000. Pěstování řízkovanců smrku, buku a dubu. In: ŠMELKOVÁ Ľ., REPÁČ I. (eds), Progresívne spôsoby pestovania sadbového materiálu. Zborník z medzinárodnej vedeckej konferencie, Zvolen, 7.–8. September 1999. Zvolen, TU: 83–89.

JURÁSEK A., 2001. Pěstební postupy pro získání výsadby schopných řízkovanců buku a dubu. Lesnický průvodce 1/2001. Jíloviště-Strnady, VÚLHM: 30.

JURÁSEK A., 2002. Současné možnosti využití metody řízkování při pěstování sadebního materiálu smrku, buku a dubu. In: Využívání vegetativně namnoženého reprodukčního materiálu lesních dřevin. Sborník přednášek z celostátního semináře, Olešná, 28.–29. 5. 2002. České Budějovice, INPROF: 11–17.

KLEINSCHMIT J., 1989. Perspektiven und Grenzen der vegetativen Vermehrung forstlichen Pflanzenmaterials. Forstarchiv, *60*: 139–145.

MAUER O., PALÁTOVÁ E., 1996. Vývoj řízkovanců buku lesního (*Fagus sylvatica* L.) po výsadbě do porostu. In: Perspektivy použití vegetativně množeného sadebního materiálu v podmínkách lesního hospodářství. Sborník referátů z odborného semináře s mezinárodní účastí, Brno, 11. 12. 1996. Opočno, VÚLHM, VS: 71–77.

MAUER O., JURÁSEK A., PALÁTOVÁ E., 2003. Root system development in sessile oak (*Quercus petraea* /Mattusch./ Lieblein) from generative and vegetative propagation. Ekológia (Bratislava) *22*, Supplementum 3: 163–175.

RADOSTA P., 1990. Zásadní technologické předpoklady výroby sadebního materiálu lesních dřevin řízkováním. Lesnictví, *36*: 579–588.

SCHACHLER G., KOHLSTOCK N., MATSCHKE J.A., WEISER F., 1987. Autovegetative Vermehrung von Alternativbaumarten für SO_2-Schadgebiete. Beiträge für die Forstwirtschaft, *21*: 1–6.

SIMPSON J.I., 2005. Vegetative propagation of American beech (Fagus grandifolia) [online]. The University of New Brunswick 2001 [cit. 15. 8. 2005]. http://digitalcommons.hil.unb.ca/dissertations/AAIMQ72509/

SPETHMANN W., 1982a. Stecklingsvermehrung von Laubbaumarten – Einfluß von Erntetermin, Substrat und Wuchsstoff. Deutsche Gartenbau, *36*: 42–48.

SPETHMANN W., 1982b. Stecklingsvermehrung von Laubbaumarten. Allgemeine Forst- und Jagdzeitung, *153*: 13–24.

ŠINDELÁŘ J., 1987. Genetické a šlechtitelské aspekty záchrany genofondu ohrožených populací lesních dřevin vegetativním množením. Lesnictví, *33*: 485–490.

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Možnosti využití řízkovanců buku lesního (*Fagus sylvatica* L.) pro stabilizaci lesních ekosystémů

ABSTRAKT: Vegetativní množení lesních dřevin má velký význam nejen ve šlechtitelských programech, ale i při záchraně cenných populací dřevin. Významná je i možnost zvýšení genetické kvality zakládaných porostů. Buk náleží ke dřevinám, které mohou podstatně zvýšit stabilitu lesních ekosystémů. O ontogenezi řízkovanců buku v lesních porostech je prozatím minimum informací. V našich pokusech, zakládaných od roku 1993, jsou již k dispozici první významné výsledky z hodnocení zdravotního stavu, fenologických projevů a růstu těchto výpěstků. Ze současných poznatků vyplývá, že se řízkovanci je možné počítat jako s prvkem stabilizujícím uměle zakládané lesní porosty včetně uplatnění geneticky přenesené kvality. Pozitivní výsledky byly získány i při hodnocení růstu řízkovanců buku druhé generace.

Klíčová slova: buk; řízkovance; výsadby; stabilizace ekosystémů

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