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Production impacts of forest tree breeding on an example of Norway spruce

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ABSTRACT: The present paper evaluates the height, diameter and stem volume of parental tree progenies. These Norway spruce progenies are compared with the control estimated from tables. The control was overperformed in all measured growth parameters. Heights of selected spruce progenies at the age of 26 years ranged from 9.2 m (K10) to 10.7 m (K2). The control height was 6.4 m. In the evaluation of diameters, progeny K4 showed the best mean dbh (13.7 cm) while the progeny K17 was rated as the thinnest (10.5 cm). We compared these data with the control diameter of 6.5 cm. The mean volumes of selected material varied from 0.097 m^3 (K9) to 0.047 m^3 (K17) while the control presented 0.0172 m^3.

Keywords: economic efficiency; forest tree breeding; growth; Norway spruce; production

Plant breeding is a systematic activity aimed to increase the production, quality and hardiness of tree species against abiotic and biotic factors (Namkoong 1988).

Recently, demand for renewable raw materials such as wood has increased, which makes forest tree breeding more significant in consequence. To make the breeding process more effective it is necessary to focus the breeding activities on breeding programs. Breeding programs are based on repeated breeding cycles and the overall effectiveness of a certain program depends on the frequency of realized cycles. Already after finishing the first breeding cycle it is possible to generate genetic gain of approximately 12% for a number of traits of economic interest and the second breeding cycle brings almost 25% (Li et al. 2000). Forest tree species are generally characterized by a high degree of intraspecific genetic variability, many commercially important traits posses a relatively high degree of heritability (Cornelius 1994a), which allows to perform economically effective breeding procedures. Simple selection of the best individuals followed by testing of their progenies generally brings increased production, in the case of trunk height and diameter about 15%. These levels of improvement depend to a certain extent on parameters influencing the selection response such as on selection intensity, heritability and trait variance (Cornelius 1994b). As expected, the economic efficiency of breeding is very much influenced by preferred breeding activities or their combinations (Thompson et al 1989; Palmer et al. 1998).

In many studies the economic efficiency of investments into forest tree breeding is evaluated on the basis of realized genetic gain. According to Vergara (2004) average realized gain in stand yield for first-generation material (*Pinus elliottii*) was approximately 10% or an extra inside-bark volume of 25 $m^3 \cdot ha^{-1}$ at 25 years.

Traditional selection systems in forestry rely on selection at young ages, usually less than the half rotation age, and application of correlated response. Percent gain estimated at young age is often assumed to

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be highly correlated with gain at rotation age (Lamberth et al. 1983; Falconer, Mackay 1996).

In addition, gains can be influenced by silvicultural measures or by market of wood substitute development. One of the means of genetic gain estimation is to use growth and production curves adjusted by site quality and seed source effect (Andersson et al. 2003).

The study of Jansson (2007) examined the relationship between height at young age (one third of the rotation period) and volume production in block-plots at older ages, and the sustainability of increased growth in volume per unit area using parent breeding values. The selection of 25% of the best parents gave a gain of 25% in volume per hectare compared with unimproved check lots.

Knowe and Foster (1989) concluded that height-age curves provided reasonable estimates of percent gain in height. Calculated gain tended to decrease during the period of crown closure. Furthermore, family rankings at all ages were consistent between observed and predicted heights. When selecting superior parent trees, however, slight differences in height have a significant impact on family rankings and which families are actually selected. Therefore, differences in growth patterns should be recognized even though differences in predicted heights are relatively small.

Williams and Matheson (1994) proposed the establishment of square test plots with the elimination of marginal trees (those trees will be omitted during statistical analysis).

Magnussen (1989) attempted to adjust family means considering the competition of neighbouring trees. Adjusted means are more reliable, allowing an easier comparison of stands and species in time. The results confirmed that large trees benefit less from dominance than small trees suffer from suppression, i.e. the competition is asymmetric.

MATERIAL AND METHODS

An experimental plot was established in close proximity of a breeding station affiliated to the Czech University of Life Sciences in Prague near Kostelec n. Č. l. It is situated around 350 m above see level, vegetation period lasts 166 days with mean annual temperature 7.7°C and annual precipitation 682 mm. The test site is located on poor mineral soils – pseudogleyic soils.

The plot was established in 1976 when 5-years-old seedlings from progenies K2, K4, K9, K10, K14, K17, K36, K40 of the Sázava River spruce were used. A total of 1,260 seedlings were used on this single experimental plot.

The first height measurements were performed on the plot in 1981 and then they were continually repeated in 1986, 1991 and 2002. In 1991 and 2002 breast height diameters (dbh) were also measured on the plot. Heights were measured with a telescopic rod to the nearest 0.1 m, diameters with a calliper (to the nearest 0.1 cm).

Biometrical characteristics from 2002 measurements were analyzed by UNISTAT software. ANO-

Table 1. Basic characteristics of selected trees progenies

Progeny	Height (m)				dbh (cm)		Volume (m^3)	Counts	Inventory (m^3)	Inventory ($m^3\cdot ha^{-1}$)
Age	5	10	15	26	15	26	26	26	26	26
K2	1.8	4.8	7.5	10.7	9.0	11.6	0.0600	21	1.260	162.1830
K4	1.8	4.4	6.3	10.5	7.4	13.7	0.0890	6	0.534	68.7347
K9	1.5	3.9	6.5	9.7	7.6	12.8	0.0970	7	0.679	87.3986
K10	1.6	4.0	6.9	9.2	7.8	11.0	0.0530	15	0.795	102.3300
K14	1.5	4.0	6.4	10.4	7.0	10.8	0.0640	12	0.768	98.8544
K17	1.5	4.1	6.9	10.0	8.0	10.5	0.0470	20	0.940	120.9940
K36	1.6	4.3	6.8	9.9	7.1	11.2	0.0580	12	0.696	89.5868
K38	1.5	4.0	6.6	9.4	7.3	13.3	0.0460	19	0.874	112.4980
K40	1.7	4.4	6.9	9.6	8.0	11.5	0.0560	15	0.840	108.1220
Control				6.4		6.5	0.0172			49.7000

dbh – diameter at breast height

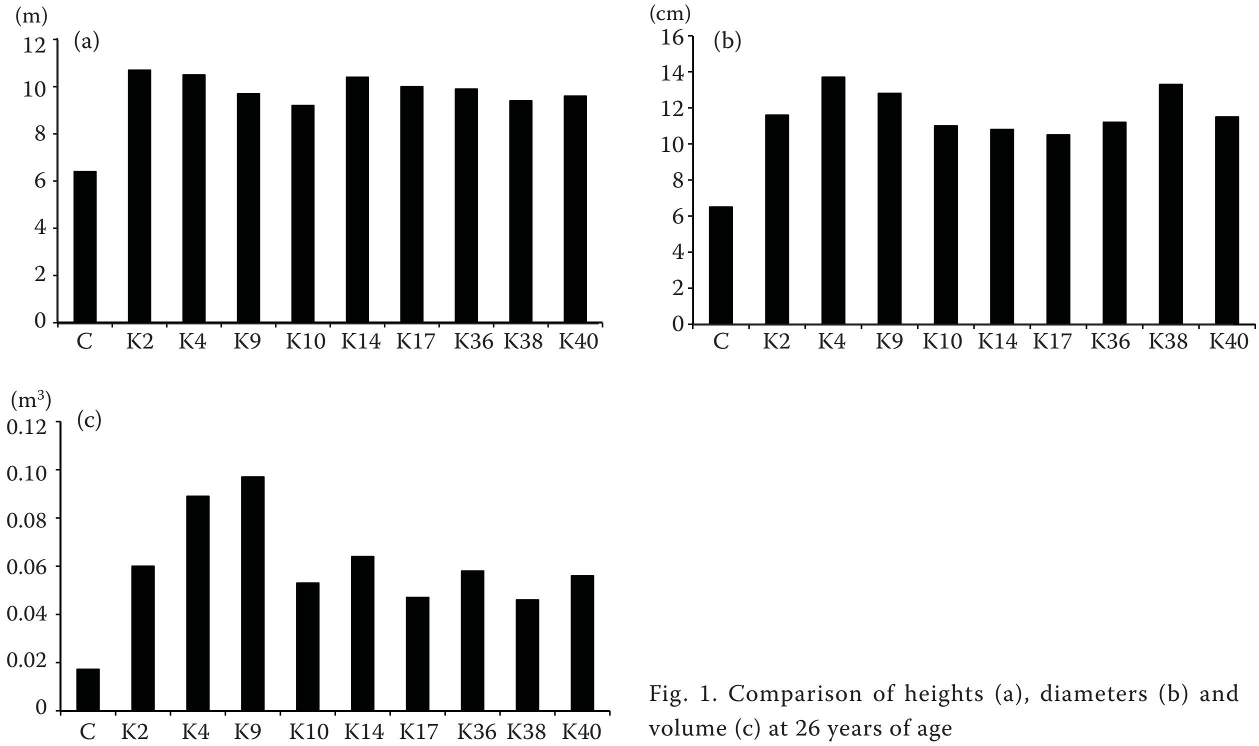

Fig. 1. Comparison of heights (a), diameters (b) and volume (c) at 26 years of age

VA was used to estimate the variability of progenies at a 95% significance level.

The control was based on growth tables (Černý et al. 1996) according to the concrete site quality and age of evaluated progenies.

RESULTS AND DISCUSSION

Basic biometrical indicators such as measured heights, diameters and calculated volume characteristics of progenies of parental trees compared to the control are presented in Table 1. Progenies are also graphically compared in Fig. 1.

The data for the control were estimated on the basis of growth tables (Černý et al. 1996) according to the concrete site quality and age of evaluated progenies.

Height

It is evident from Table 1 and Fig. 1 that the heights of selected spruces at the age of 26 years varied from 9.2 m (K10) to 10.7 m (K2). Height variability of progenies is not statistically significant (Table 2). The height of the control was 6.4 m, which is a very important difference in comparison with selected progenies from the breeding program.

Diameter

Similar results were also obtained by the evaluation of mean diameters (Table 1; Fig. 1). In terms of diameters, progeny K4 showed the best results on average (13.7 cm). Within the selected progenies, spruce marked K17 was rated as the thinnest on average (10.5 cm). A difference between these two extremes was 23% and was statistically significant (Table 2). Variability of dbh is statistically significant (Table 2).

The diameter of the control was determined to be 6.5 cm, which represents only about 47% of the best progeny K4 and 62% of the worst progeny K17 included in breeding.

Stem volume

The most pronounced differences were obtained comparing the volumes of the control and selected material at the age of 26 years (Table 1; Fig. 1). The mean volumes of selected material ranged from 0.097 m^3 (K9) to 0.047 m^3 (K17). The variability of progenies in terms of stem volume was not statistically significant (Table 2). The control reached the volume of 0.0172 m^3. This is 5.7 times less than the average of progeny K9.

CONCLUSIONS

There are not many references dealing with the economic efficiency of forest tree breeding in the Central European region. Therefore, possibilities of confronting our results with comparable studies

Table 2. Results of ANOVA

Source of variability	Sum of Squares	Degrees of Freedom	Average Square	*F*-value	Significance level
Height					
Progeny	75.127	8	9.391	0.974	0.4553
Replication	30.080	1	30.080	3.120	0.0779
Explained error	105.206 4,993.596	9 518	11.690 9.640	1.213	0.2845
Total	5,098.803	527	9.675		
dbh					
Progeny	261.026	8	32.628	2.066	0.0375
Replication	133.656	1	133.656	8.462	0.0038
Explained error	394.683 8,182.036	9 518	43.854 15.795	2.776	0.0035
Total	8,576.719	527	16.275		
Volume					
Progeny	0.052	8	0.007	1.728	0.0892
Replication	0.017	1	0.017	4.435	0.0357
Explained Error	0.069 1.949	9 518	0.008 0.004	2.029	0.0344
Total	2.018	527	0.004		

dbh – diameter at breast height

from our geographical conditions are mostly restricted. To be able to perform the evaluation of economic profitability of a breeding program it is necessary to realize the complex biometric analysis of experimental plots in the first step. The actual economic evaluation of this progeny test will therefore be realized in the next step of this research problem.

The problems of the evaluation of economic profitability and genetic gain are solved on a much higher level in Scandinavian countries, above all in Sweden. Experience of many breeding cycles has been gained in transatlantic states, mainly in the USA.

The results of our experiment (this paper presents the first income data of the research project ending in 2012) show significant differences between the evaluated progenies and the control.

We can realistically presume from these results that the effect of the economic income of breeding will be clearly visible already at the early growth stages.

Our data obtained from young forest stands at the age of 26 years indicate a possibility to harvest higher volumes per unit area thanks to the use of selected material. The material from selected parental trees overperformed the control in all biometrical characteristics including mean heights, mean diameters and mean volumes.

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