JOURNAL OF FOREST SCIENCE, *50*, 2004 (1): 17–23

Breeding value of Norway spruce (*Picea abies* [L.] Karst.) from the Kłodzko Forest District (SW Poland)

R. ROŻKOWSKI

Polish Academy of Sciences, Institute of Dendrology, Kórnik, Poland

ABSTRACT: This is the first report on measurements and observations of an experimental plot of 35-year-old Norway spruce, established in 1970 by the Institute of Dendrology at Kórnik, where progenies of 22 plus trees from the Kłodzko Forest District were planted. The experiment was established in an incomplete block design of 20 families with 3 replications. Survival rate and growth traits determining productivity (plant height or basal area – stem cross-sectional area at breast height per 1 ha) were assessed in several years, and qualitative traits (trunk straightness; degree of natural pruning; thickness, length and angle of branches; crown density; presence of galls caused by the aphids *Adelges laricis* Vall. and *Sacchiphantes viridis* Ratz.) were evaluated once in 2001. Analysis of variance revealed significant differences between the half-sib families in survival rate and productivity but no significant differences in qualitative traits. Statistically significant positive correlations were found between trunk straightness at the age of 36 years and height of 2-year-old seedlings in the nursery, and between the degree of natural pruning at the age of 36 years and both tree height at the age of 9 years and basal area at the age of 13 years.

Keywords: plus trees; progenies; qualitative traits; productivity; survival rate; heritability

Norway spruce from the Kłodzko Valley in the Sudetes Mountains is tested in several Polish and international provenance experiments, including:

- series IUFRO 1964–68; author Prof. O. Langlet; populations – Kłodzko (0414, 0781, 0132), Stronie Śląskie (1008, 0553), Bystrzyca Kłodzka (0292), Szczytna Śląska (0930, 1150);
- series ID PAN Kórnik 1969; author Prof. M. Giertych; population – Stronie Śląskie (S-15-125);
- series IUFRO 1972; author Prof. S. Tyszkiewicz; populations – Stronie Śląskie (9), Międzygórze (8).

In respect of productivity, populations from that region are regarded as average, which is confirmed by the results of most provenance experiments (GIERTYCH 1976, 1978, 1997; MATRAS 1993, 2002; RAU et al. 1998; ROŻKOWSKI et al. 2001), although on some plots, e.g. at Siemianowice, the populations from Kłodzko are in the best group (BARZDAJN et al. 1990). On two plots of the IUFRO series 1964–68 in the Czech Republic, a population from Szczytna Śląska (No. 1150) reached the values close to average for these experiments (VINŠ, VANČURA 1977, 1979).

A negative intrapopulation correlation between the height of individual trees in 1969 and 1972 for 4 of the 8 tested populations (0132, 0781, 0414 and 0930) suggests that many local populations in the Kłodzko Valley are mixtures of native and alien populations (GIERTYCH 1978). Some other researchers have similar opinions. MATRAS (2002) claimed that the low breeding value of Norway spruce from the Kłodzko Valley might be due to the fact that seeds collected in Germany and Austria were sown there in the 19th century. SCHÖNBACH (1950) believed that in that region there were some good native populations, but also some alien populations planted there in 1879–1928. For example, a good population has been found near Bystrzyca Kłodzka (No. 0292). Numerous international experiments show that seedlings originating from this population grow very well everywhere except on three experimental plots (Norway, Germany and Belgium). Also on a comparative plot in France all populations from the Kłodzko region reach high or average values (MATRAS 2002).

In the series of experiments established in 1969, the population from Stronie Śląskie, evaluated at the age of 28 years was one of the best in terms of growth traits on plots at Międzylesie (Poland), and at St. Ignace (Canada). However, on comparative plots at Kórnik and Orawa (Poland), the population reached only the values close to average, while at Gołdap (Poland), and both Lac Dore and Valcartier (Canada), it grew slowly (CORRIVEAU et al. 1989; GIERTYCH, KRUPSKI 1996).

In the IUFRO series 1972, on plots in Poland, the values of growth traits of Norway spruce from Międzygórze (8) are much above average, while those from Stronie Śląskie (9) are just average. Both populations give the best results on the plot at Siemianice, and the worst at Głuchów (BARZDAJN et al. 1990; MATRAS 2002). On plots established in Germany, Finland, Norway, Croatia, and Canada,

both populations usually rank much above average, while in France and Belgium they are average (MATRAS 2002). In Slovakia, relatively good results were recorded for the population from Międzygórze, whereas the population from Stronie Śląskie is below average (HOLUBČIK 1980; PACALAJ et al. 2002).

The objectives of this study were: (1) to analyse the genetic variability of Norway spruce half-sib families from the Kłodzko Forest District; and (2) to assess the possibility of selection on the family level in respect of breeding value.

MATERIALS AND METHODS

The progeny experimental plot of Norway spruce from the Kłodzko Forest District was established in the 'Zwierzyniec' Experimental Forest, Institute of Dendrology, Kórnik. In 1966 the Institute received seeds of 22 plus trees selected by Mr. Wilczkiewicz, the head of the Kłodzko Forest District. Unfortunately, no detailed information on those trees is available. The seeds were sown in a nursery in April 1966, where they stayed for 4 years. In the spring of 1970, the seedlings were transplanted to the experimental plot (Fig. 1). The experiment was established in an incomplete block design with 3 replications; block I lacked families 18 and 30, block II lacked families 20 and 24, and block III lacked families 4 and 25.

In 1974, 1978, 1987, 1991 and 2001, survival rate was assessed. The first measurements of plant height were made in the nursery in 1966 and 1967, and next ones on the experimental plot in 1974, 1978, and 1987. Diameter at breast height was also measured to calculate basal area – stem-cross sectional area per 1 ha (BA) in 1978, 1987, 1991, and 2001, as it reflects the productivity of each family.

In 2001, the following qualitative traits were evaluated on a scale 1–3:

- thickness of primary branches (1 = thick ÷ 3 = thin),
- length of primary branches (1 = long ÷ 3 = short),
- angle of primary branches (1 = acute angle ÷ 3 = right angle),
- trunk straightness (1 = crooked ÷ 3 = straight),
- degree of natural pruning (1 = poor ÷ 3 = good),
- crown density (1 = thin ÷ 3 = dense).

Additionally, the presence (1) or absence (0) of galls caused by two aphid species (*Adelges laricis* Vall. and *Sacchiphantes viridis* Ratz.) was recorded.

To ensure the orthogonality of the model, calculations were made only for 11 families that were fully represented in all three blocks. The studied traits in individual years were subjected to analysis of variance, and the significance of differences between the families was assessed. The values of traits in % were expressed as arc measure, and mean values for each family (except survival rate) were expressed in units of standard deviation. Family means and significance levels of Snedecor's *F* test are presented in Tables 1, 2 and 3. Analysis of Pearson's linear correlation was also carried out for the studied traits, and the values of coefficients of variation were calculated for individual traits on the basis of absolute values.

The analysis of variance was made on a model based on the following distribution of factors:

$$Y_{ijn} = \mu + F_i + B_j + FB_{ij} + E_{n(ij)}$$

where: Y_{ijn} – relative value of each of the studied traits,
μ – general mean,
F_i – effect of *i*-th family,
B_j – effect of *j*-th block,
$E_{n(ij)}$ – random error.

Expected mean squares for each factor were also estimated according to GIERTYCH (1991):

F_i	$\sigma^2_E + x\sigma^2_{FB} + bx\sigma^2_F$	=	A
B_j	$\sigma^2_E + x\sigma^2_{FB} + rx\sigma^2_B$	=	B
FB_{ij}	$\sigma^2_E + x\sigma^2_{FB}$	=	C
$E_{n(ij)}$	σ^2_E	=	D

and on this basis, the family and individual heritabilities of individual tree basal areas were calculated from the equations recommended by FALCONER (1974):

$$h^2_F = \frac{A - C}{A} \quad \text{and} \quad h^2_S = \frac{4\sigma^2_F}{\sigma^2_P}$$

where: $\sigma^2_P = \sigma^2_F + \sigma^2_{FB} + \sigma^2_E$

RESULTS AND DISCUSSION

Survival rate

In respect of this trait, a significant variance between the Norway spruce families was observed at the age of 26 and 36 years (Table 1). Different families ranked first and last in different years. At the age of 26 years, family 37 was the best (55.56%) and family 27 was the worst (33.33%). Ten years later, family 2 was the best (40.74%), families 1, 22 and 37 ranked the second (33.33%), while family 28 was the worst (14.81%). The mean survival rate decreased from 96.63% at the age of 9 years to 26.26% at the age of 36 years.

Coefficient of variation (CV) for this trait increased systematically from 3.82% at the age of 9 years to 29.74% at the age of 36 years. This indicates an increasing polarization of families in terms of survival rate, which may reflect their adaptability to the local environmental conditions (Table 1).

Growth traits

No significant differences between the families were detected in respect of plant height at the age of 1 and

Table 1. Mean survival rate

Family No.	Survival rate (%)				
	1974 (9 years)	1978 (13 years)	1987 (22 years)	1991 (26 years)	2001 (36 years)
1	92.59	92.59	55.56	44.44	33.33
2	96.30	96.30	44.44	44.44	40.74
22	100.00	100.00	55.56	48.15	33.33
23	88.89	88.89	66.67	44.44	18.52
26	100.00	100.00	55.56	48.15	29.63
27	100.00	100.00	44.44	33.33	22.22
28	100.00	100.00	51.85	44.44	14.81
31	100.00	100.00	48.15	40.74	18.52
34	96.30	96.30	55.56	51.85	22.22
37	92.59	88.89	59.26	55.56	33.33
38	96.30	96.30	51.85	44.44	22.22
CV (%)	3.82	4.34	11.57	12.09	29.74
p	0.682	0.705	0.086	0.031*	0.041*

CV – coefficient of variation; *p* – probability for *F* test of differences between families; * – significant $p \leq 0.05$

Table 2. Mean height and stem-cross-sectional area at breast height (basal area – BA)

Family No.	Tree height			BA (m^2/ha)			
	1966[1] 1 year	1967[1] 2 years	1974[2] 9 years	1978 13 years	1987 22 years	1991 26 years	2001 36 years
1	4.38	15.35	183.40	9.07	31.56	35.50	50.45
2	3.69	13.24	195.19	10.13	36.36	51.26	95.08
22	3.81	15.13	165.00	8.15	24.06	27.61	32.15
23	3.78	14.77	129.79	4.56	22.37	24.92	26.90
26	3.58	12.81	154.44	6.71	22.86	28.03	29.71
27	3.62	14.49	190.19	10.36	23.35	26.51	33.30
28	3.25	15.18	182.41	9.11	20.51	22.48	14.72
31	3.40	13.85	212.78	12.21	28.60	33.37	23.04
34	4.35	15.72	191.92	8.60	25.09	32.72	23.25
37	4.20	16.41	153.20	5.13	26.83	37.62	49.71
38	3.67	14.43	192.50	9.62	29.26	32.60	29.14
CV (%)	9.31	6.92	12.91	26.79	17.70	24.63	59.46
p	–	–	0.046*	0.129	0.139	0.036*	0.0002*

[1] – in cm; [2] – in m; other explanations – see Table 1

Table 3. Mean family values for qualitative traits at age of 36 (in standard deviation units)

Family No.	Primary branches			Stem		Crown density
	thickness	length	angle	straightness	pruning	
1	1.001	0.588	0.234	0.792	–0.130	–1.275
2	–0.804	–1.404	0.994	–1.963	0.780	1.731
22	–1.525	–1.635	–0.364	–1.228	–0.130	–1.275
23	1.145	0.779	0.114	–0.420	–0.954	0.803
26	0.820	1.064	–0.289	–0.723	–1.086	–0.153
27	–0.804	0.112	0.831	0.792	0.459	1.087
28	–0.804	–0.365	–0.962	0.792	–0.424	–0.684
31	0.495	0.207	–0.962	–0.420	0.106	–0.897
34	–0.804	–0.841	–1.858	0.792	0.459	–0.330
37	–0.082	–0.047	1.429	0.792	–1.307	0.615
38	1.361	1.541	0.831	0.792	2.225	0.378
p	0.534	0.448	0.938	0.107	0.723	0.530

p – probability for *F* test of differences between families

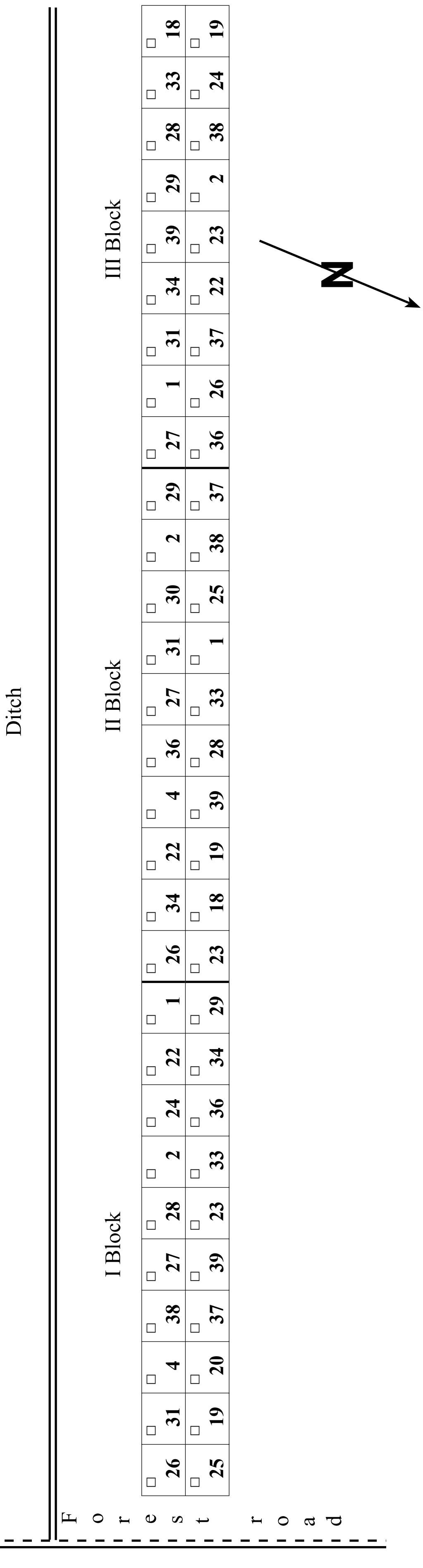

Fig. 1. Lay-out of the experimental plot with Norway spruce half sib families from the Kłodzko Valley, planted in Kórnik in 1970

□ – concrete poles with family number; 1 – family number; 9 trees per plot planted in 1.2 × 1.2 m spacings

2 years in the nursery. Significant differences in this trait were recorded only in 1974, when the trees were 9 years old (Table 2). BA, reflecting productivity, significantly differentiated the families in 1991 and 2001 (at the age of 26 and 36 years). The differences were particularly conspicuous in the last year of measurements, i.e. 2001. In that year, the high significance level and the high value of coefficient of variation (CV = 59.46%) for this trait (Table 2) were due mainly to the marked dominance of family 2, which had systematically improved its position in the ranking of growth traits since the age of 2 years (Fig. 2). Families 1 and 37 ranked the second, while the other families (22, 23, 26, 27, 28, 31, 34, 38) had much lower values of this trait. Family 34, initially one of the best, continuously decreased its productivity (Fig. 2).

In this experiment, differences in growth traits between the families increased with time, which indicates the prolongation of a distance between the best and the worst families.

Qualitative traits

No significant differences between the families were detected in the studied qualitative traits (Table 3), which suggests that they depend mainly on environmental conditions.

Correlations between traits

Survival rate in 1974 (when the trees were 9 years old) was positively correlated with the values of this trait in 1978 but survival rate recorded in 1987 was negatively correlated with both earlier assessed rates (Table 4). This results from thinning and a rapid decrease in the number of trees between 1978 and 1987 (Table 1), probably because of the excessive density of the canopy. Significant negative correlations were also observed between plant height both in 1966 and 1974 and their survival rate in 1978 and 1987 (Table 4). BA in 1978 was positively correlated with survival rate in 1974 and 1978, but after the rapid decline in the number of trees, a negative correlation between the two traits was recorded in 1987 and 1991 (Table 4).

Plant height in the nursery in 1966 and 1967 (when the seedlings were 1 and 2 years old) was not correlated with plant height and BA in the following years. However, there were very strong correlations between plant height in 1974 and BA in 1978, and between BA in 1987, 1991 and 2001 (Table 4).

Qualitative traits (except the occurrence of galls caused by two aphid species) were not correlated with survival rate, but some significant positive correlations with growth traits were recorded, especially for trunk straightness and degree of natural pruning as well as with the occurrence of galls. The higher were 2-year-old seedlings, the straighter were tree trunks in 2001 (at the age of 36 years). Moreover, the higher were the trees in 1974 (at the age of 9 years) and the larger was their BA in 1978, the higher was the degree of natural pruning in 2001 (at the age of 36 years) and the larger was the number of galls (Table 4).

Table 4. Matrix of Pearson's correlation coefficient ($N = 11$; bold values are significant at $p \leq 0.0$)

No.	Trait	Survival rate					Height			BA				Qualitative traits in 2001					
		Trait No.																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1.	Survival rate 1974																		
2.	Survival rate 1978	**0.97**																	
3.	Survival rate 1987	**–0.68**	**–0.67**																
4.	Survival rate 1991	–0.32	–0.43	0.57															
5.	Survival rate 1974	–0.13	–0.19	–0.11	0.34														
6.	Height 1966	–0.59	**–0.61**	0.41	0.53	0.44													
7.	Height 1967	–0.41	–0.50	0.44	0.44	–0.11	**0.60**												
8.	Height 1974	0.52	0.55	**–0.83**	–0.41	–0.09	–0.17	–0.19											
9.	BA 1978	**0.62**	**0.67**	**–0.87**	**–0.60**	–0.12	–0.35	–0.34	**0.96**										
10.	BA 1987	–0.21	–0.19	–0.41	–0.01	**0.63**	0.27	–0.22	0.47	0.40									
11.	BA 1991	–0.21	–0.24	–0.36	0.20	**0.73**	0.31	–0.18	0.35	0.23	**0.92**								
12.	BA 2001	–0.25	–0.27	–0.32	0.07	**0.84**	0.25	–0.23	0.10	0.06	**0.81**	**0.90**							
13.	Branch thickness	–0.48	–0.42	0.38	–0.04	–0.19	0.05	–0.21	–0.20	–0.20	0.14	–0.05	–0.14						
14.	Branch length	–0.26	–0.23	0.26	–0.19	–0.38	–0.10	–0.18	–0.18	–0.17	–0.13	–0.31	–0.35	**0.91**					
15.	Branch angle	–0.35	–0.43	–0.09	–0.10	0.50	0.08	–0.04	–0.22	–0.21	0.41	0.41	0.60	0.20	0.21				
16.	Stem straightness	–0.15	–0.20	0.13	0.00	–0.49	0.29	**0.63**	0.10	–0.03	–0.32	–0.39	–0.50	0.21	0.44	–0.05			
17.	Natural pruning	0.22	0.30	–0.56	–0.37	–0.06	–0.10	–0.19	**0.68**	**0.65**	0.46	0.28	0.13	0.02	0.05	0.08	0.08		
18.	Crown density	–0.27	–0.29	–0.19	–0.17	0.18	–0.10	–0.26	–0.13	–0.16	0.25	0.41	0.53	0.00	0.04	**0.63**	–0.18	0.17	
19.	Galls	0.42	0.45	**–0.75**	–0.51	–0.01	–0.24	–0.46	**0.69**	**0.70**	0.34	0.38	0.26	–0.28	–0.28	–0.16	–0.25	0.27	0.26

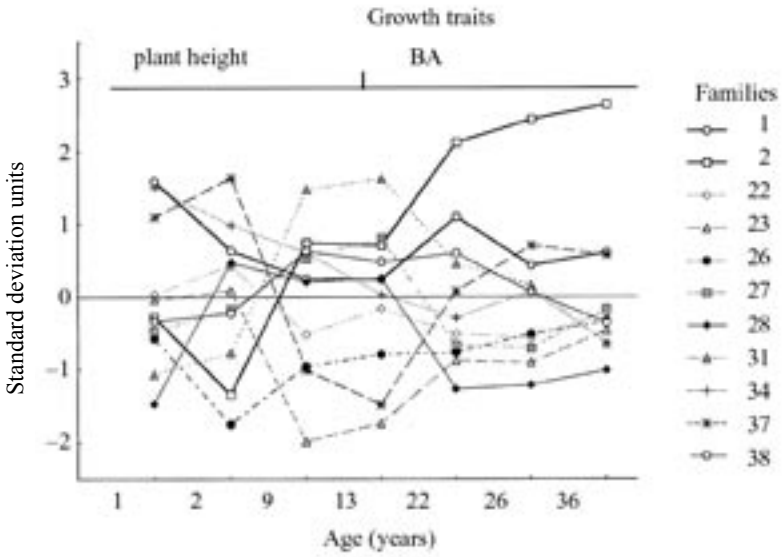

Fig. 2. Productivity of Norway spruce families depending on age

As a rule, Norway spruce develops straight trunks and the highest trees have both the highest quality and the fastest growth rate (SZYMAŃSKI 1998). Correlations between qualitative and growth traits indicate a possibility of very early selection of Norway spruce in respect of straight trunks and degree of natural pruning that affect wood quality.

Heritability

Selection of families or individuals for further breeding should be based on traits that depend mainly on genetic, not environmental factors. Growth traits, affecting productivity, are very important, so it is advisable to estimate their heritabilities. In this experiment, only heritability of individual tree basal areas was estimated. Family and individual heritability of individual basal area in 1991 reached $h^2_R = 0.714$ and $h^2_S = 0.705$, respectively. These values are lower than those reported earlier for Norway spruce from lowlands in southern Poland, ranging from 0.82 to 0.86 on different plots (KRUPSKI, GIERTYCH 1997).

The high values of heritability recorded in this study create a possibility of family and individual selection of fast-growing Norway spruce from the Kłodzko Forest District.

Fig. 3. Progeny of Norway spruce plus-trees from Kłodzko Valley on the experimental plot in Kórnik (photo by R. Rożkowski)

CONCLUSIONS

On the basis of observations made for 36 years, the following conclusions can be drawn:

- there exist significant differences in survival rate and growth traits between Norway spruce families derived from plus trees growing in the Kłodzko Forest District;
- trees that grew faster in the nursery (at the age of 2) were characterised by straighter trunks at the age of 36 years, and those that grew faster at the age of 9 years had a higher degree of natural pruning at the age of 36 years;
- high levels of family ($h_F = 0.714$) and individual ($h_S = 0.705$) heritability in Norway spruce suggest that it is possible to select native plus trees with a high productive value.

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Received for publication June 23, 2003
Accepted after corrections December 5, 2003

Šlechtitelská hodnota smrku ztepilého (*Picea abies* [L.] Karst.) z Lesní správy Kłodzko (JZ Polsko)

R. ROŻKOWSKI

Polska Akademia nauk, Instytut dendrologii w Kórniku, Kórnik, Polska

ABSTRAKT: Příspěvek je první informací o měření a pozorování smrku ztepilého ve věku 35 let na experimentální ploše založené Ústavem dendrologie v Kórniku. Na plochu byla vysázena potomstva 22 elitních stromů smrku ztepilého z Lesní správy Kłodzko. Pokus byl uspořádán metodou neúplných bloků s trojím opakováním z 20 potomstev. Po několik let se stanovovala míra přežívání a znaky charakterizující produkci, tj. výška stromů nebo výčetní základna. Kvalitativní vlastnosti (přímost kmene, stupeň jejich přirozeného čištění, tloušťka, délka a úhel větví, hustota koruny, výskyt hálek způsobený korovnicemi) se hodnotily jen jednou, a to v roce 2001. Analýza rozptylu odhalila průkazné rozdíly v ujímavosti a produkci mezi polosesterskými potomstvy. Průkazná pozitivní korelace byla zjištěna mezi přímostí kmene ve věku 36 let a výškou dvouletých stromků a mezi stupněm přirozeného čištění kmenů ve věku 36 let a stromovou výškou ve věku devíti let a také výčetní základnou ve věku 13 let.

Klíčová slova: smrk; elitní stromy; potomstva; kvalitativní znaky; produkce; míra přežívání; dědivost

Corresponding author:

Mgr. Ing. ROMAN ROŻKOWSKI, Polish Academy of Sciences, Institute of Dendrology, ul. Parkowa 5, 62-035 Kórnik, Poland
tel.: + 061 817 00 33, fax: + 061 817 01 66, e-mail: idkornik@rose.man.poznan.pl