Among-population Variation in Quality Traits in Two Romanian Provenance Trials with *Picea abies* L.

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Abstract

The descendants of 33 Norway spruce seed stands were evaluated at 30 years after plantation time, in two field trials established in different environmental conditions: outside of the natural range (ONR), at low altitude (Câmpina trial), and in natural distribution area (INR – Gurghiu trial), in Romania. Evaluations have been made concerning the most important growth, stem and branches characteristics: diameter at breast height (DBH), pruning height, pruning height ratio, trees slenderness coefficient, crown diameter, crown slenderness index, branches diameter and branches finesse. Highly significant differences ($p < 0.001$) were found among populations in both trials for most of the analysed traits (except DBH). Significant differences between Carpathian branches were recorded for most of the analysed traits, with a higher level in Câmpina comparative trial, suggesting different reactions of populations to the more adverse site conditions existing in the ONR trial. For all of the analysed traits, the populations showed superior results from a forestry point of view in the trial located in ecological optimum of Norway spruce (Gurghiu). Outside the natural range (Câmpina trial), populations present high values for slenderness trees, crown diameter and branches thickness, which increases the Norway spruce vulnerability to disruptive action of the abiotic factors such as wind and snow. Joint selection of Norway spruce populations for quantitative and quality traits is contraindicated. The two-stage selection strategy is applicable in this situation. Pruning height had the highest Q_{ST} estimates.

Key words: comparative trials, correlations, DBH, seed stands, stem and crown traits

Introduction

In the countries with an advanced silviculture, comparative trials were established for the main forest species. A category of such trials includes the provenance and progeny tests, assessing the growth traits (tree height, diameter at 1.30 m, etc.), quality of the trunk and crown traits (pruning height, diameter of branches, etc.) and adaptive trait (survival rate). These traits are important for a better knowledge of the populations' adaptability to the change of the environmental conditions, knowing that Norway spruce is one of the most vulnerable trees to the change of the climate conditions (Stakėnas et al. 2012). Also, these are traditional traits studied in provenance trials.

In two field trials, one established in ecological spruce distribution (Gurghiu), and the other located outside of the Norway spruce natural distribution range (Câmpina), 33 Norway spruce (*Picea abies* L.) Karst) populations were tested, at 30 years after plantations time. Establishing of the trials outside of the natural area was performed in the period when there was a strong trend for Norway spruce expansion in Europe, in order to find out in a short time which are the populations that show high capacity for growth under different environmental conditions, and what are the risks that might occur.

As a result of evaluations from this study, valuable populations will be classified as tested seed sources. In the future, they will provide seeds with superior genetic properties for afforestation in forest sites with similar characteristics to those two experiments. In Romania, only tested seed sources are allowed for seed transfer from the region of origin to other regions where they were tested. Using the forest reproductive material from tested populations will help to increase the productivity and genetic diversity of forests.

At the same time, the data obtained will be complementary to those obtained in Norway spruce provenance trials established in various European countries (Bulgaria, Finland, France, Poland, Romania, Scotland, Sweden and Hungary), where many provenances originating from the Romanian Carpathians have performed well (Héois and Van de Sype 1991, Giertych 1993, Alexandrov and Stancova 1997, Matras 1997, Naapola 1997, Karlsson and Hogberg 1998, Enescu and Ioniтor 2002, Skrøppa 2005, Ujvari and Ujvari 2006).

The objectives of the present study are concerned with the following topics:

- to analyse the performance of the 33 populations under different sites conditions, in trials established inside of the natural range (INR) and outside of the natural range (ONR – at low altitude);
- to evaluate the behaviour of local provenances and the adaptability of the provenance 5-Moldoviţa, which has been designated as standard IUFRO provenance, in 1996;
- to determine how the populations originating from different branches of the Romanian Carpathians react under different sites conditions;
- to calculate the correlations between analysed traits and between traits and the ecological gradients of the seed stands origins.

Grouping populations by appurtenance to one of the Carpathian branches was undertaken to identify some common features of populations from the same region. It seems that each Romanian Carpathians division has represented a distinct glacial refuge for Norway spruce, which has generated some distinct characteristics of populations in these areas: in the Eastern Carpathians there are spruce trees with the resonance wood characteristics, while in the Western Romanian Carpathians the spruce ideotype with narrow crown was found.

Materials and Methods

Romanian Carpathians have a 3 degree northern latitude (45-48) and 4.5 degrees eastern longitude (22-26.5) extension, the northern branch being represented by the Eastern Carpathians while in south the Southern Carpathians are found. The average altitude is 1000 m in the Eastern and Curvature Carpathians, 1150 m in Southern and about 600 m in the Western Carpathians. The Eastern Carpathians are characterized by an important volcanic chain (Oaş - Harghita), in Western Carpathians extensive karst surfaces are found, while in Southern the landscape is almost similar to the Alps. Some of the highest peaks of the entire Carpathians (e.g. Moldoveanu = 2,544 m) are found in the Southern Carpathians. Mean annual temperature and precipitation are similar to the first three divisions (3-6°C and 700-1000 mm rainfall), while in the Western Carpathians the average temperature is slightly higher, ranging between 8 and 10°C.

The 33 seed stands were selected in Romanian Carpathians in order to have at least one valuable population from each region of provenance (Table 1). In the spring of 1980, Câmpina and Gurghiu trials were established, using bulked seeds harvested from 10 trees for each of the 33 populations (Enescu and Ioniтor 2002). The ten trees were chosen based on their representativeness for the populations, and another criterion was to be growing at a minimum distance of at least 50 m from each another. The aim was to encompass the diversity of the population and to avoid inbreeding.

Table 1. Location of the tested populations (Şofletea et al. 2012)

Code	Seed sources (Region of provenance*)	Altitude [m]/ latitude [N]/ longitude [E]/	Code	Seed sources (Region of provenance)	Altitude [m]/ latitude]N]/ longitude [E]/
1	Coşna (A)	1025/47°28'/25°10'	18	Braşov (B)	1020/45°35'/25°35'
2	Dorna Candreni (A)	990/47°17'/25°05'	19	Azuga (B)	1210/45°28'/25°40'
3	Frasin (A)	755/47°28'/25°48'	20	Domneşti (C)	650/45°11'/24°49'
4	Marginea (A)	670/47°49'/25°50'	21	Orăştie (C)	680/45°43'/23°16'
5	Moldoviţa (A)	855/47°39'/25°34'	22	Bistra (C)	1350/45°35'/23°45'
6	Stulpicani (A)	985/47°22'/25°46'	23	Voineasa (C)	1410/45°17'/23°55'
7	Năsăud (A)	1210/47°28'/24°25'	24	Retezat (C)	970/45°27'/22°51'
8	Prundul Bârgăului (A)	1290/47°05'/24°45'	25	Bozovici (D)	600/44°57'/21°59'
9	Rodna (A)	890/47°26'/24°50'	26	Văliug (D)	940/45°12'/22°02'
10	Sânmartin (A)	900/46°13'/25°57'	27	Beliş (E)	1210/46°32'/23°02'
11	Topliţa (A)	910/46°45'/25°20'	28	Turda (E)	1200/46°33'/23°02'
12	Gurghiu (A)	1225/46°45'/24°50'	29	Beiuş (E)	520/46°52'/22°23'
13	Sovata (A)	1190/46°40'/25°05'	30	Dobreşti (E)	510/46°53'/22°20'
14	Tarcău (A)	930/46°54'/26°06'	31	Sudrigiu (E)	1050/46°31'/22°35'
15	Comandău (B)	1150/45°45'/26°20'	32	Câmpeni (E)	1237/46°25'/23°10'
16	Nehoiu (B)	1120/45°37'/26°30'	33	Gârda (E)	1295/46°29'/22°55'
17	Nehoiaşu (B)	1080/45°30'/26°10'			

* Region of provenance established in Romania: A – Eastern Carpathians; B – Curvature Carpathians; C– Southern Carpathians; D – Banat Mountains; E – Apuseni Mountains; D+E – Western Romanian Carpathians

The Câmpina trial was established outside of the Norway spruce natural range, in Curvature Subcarpathians region, at 570 m altitude (300 m below the lower altitudinal limit of spruce). The geographical coordinates of the testing site are: 45°11'11" N and 25°48'47" E. The average annual temperature is 9.3°C while the mean annual precipitations are 645 mm (ANM 2011). The Gurghiu trial is located within the Norway spruce natural distribution, in Eastern Carpathians, at an altitude of 1000 m, in the mountainous mixed stands vegetation. The geographical coordinates of the testing site are 46°48'13" N and 25°03'58" E. The average annual temperature is 5.7°C, and the value for mean annual precipitations is 810 mm (ANM 2011).

In both trials the experimental design was an incompletely balanced square grid design, type 6 × 6, with 3 replications and 49 seedlings per plot planted at 2 × 2 m spacing (Şofletea et al. 2012).

According to the IUFRO recommendations (Lines 1967), in each unitary plot (33 populations plus three populations which are repeated for covering the experimental design) ten trees were assessed. Consequently, the number of trees from each population measured in every trial is 30. The trees were randomly chosen after a pre-set schedule.

The following traits have been measured for 1080 trees per comparative trial:

- Diameter at breast height (DBH) and diameter at 2.2 m (D) from the ground, immediately below to the nearest whorl;
- Tree height (TH) and pruning height (PH), using a Vertex III instrument;
- Crown diameter (CD), by measuring the ground projection of crowns in two perpendicular directions (N-S and E-V);
- Dominant branch diameter (DBD), in whorls situated at 2.2 m from the ground, measured with the electronic callipers. In order to ensure the accessibility in the trials dry branches below the height of 2.2 m were removed.

The following derived traits were also calculated:

- Tree slenderness coefficient: TSC = TH / DBH;
- Pruning height ratio: PHR = (PH / TH) • 100;
- Crown slenderness index: CSI = TH / CD;
- Branches finesse: BF = (DBD / D) • 100.

The normal distribution was checked with the Kolmogorov - Smirnov test and Levene's test was used to assess variance homogeneity for applying ANOVA. Applying ANOVA test, the variance components were estimated under the influence of populations, groups and replications well as the residual variance. The mathematical-statistical model of analysis was developed starting from the one recommended by Nanson (2004):

$$X_{ijk} = m + \alpha_i + \beta_j + \gamma_k + \varepsilon_{ijk}$$

where: m is overall average value, α_i is component of i^{th} population (i = 1...a), β_j is component of j^{th} replicate (j = 1...b), γ_k is component of k^{th} group (Carpathians branches) and ε_{ijk} is random error affecting ijk plots.

The population × location interaction and the influence of test site variation were estimated using the bifactorial ANOVA model (Nanson 2004):

$$X_{ijk} = m + \alpha_i + \beta_j + \gamma_k + \alpha\beta_{ij} + \beta\gamma_{ik} + \varepsilon_{ijk}$$

where: m, α_i and γ_k are as above, β_j is component of j^{th} locations (j = 1...b), $\alpha\beta_{ij}$ is interaction of i^{th} population with j^{th} location, $\beta\gamma_{jk}$ is interaction of k^{th} group with j^{th} location. The variance components (%) were also estimated using Statistica, ML method.

The level of significance was established using *Fisher's* (F) test. Pearson simple correlations between analysed traits and between traits and the geographic data of the population origins, were also determined. The corrected latitude takes into account both latitude and altitude according to Viersma (1962): Le = L+A/100. One hundred meters difference in altitude is equal to a difference of one degree in latitude.

To estimate the quantitative genetic differentiation among populations, for all of the analysed traits, Q_{ST} coefficients were calculated, using the formula proposed by Morgan et al. (2005):

$$Q_{ST} = \frac{\sigma_b^2}{\sigma_b^2 + 2\sigma_w^2}$$

where $\sigma_b{}^2$ and $\sigma_w{}^2$ are the between and within populations genetic variances.

Results

Diameter at breast height (DBH)

The average value of DBH in the Câmpina comparative trial is 16.0 cm, while the value of this trait is 8% higher (17.3 cm) in the trial installed in the species optimum (Gurghiu). The Nehoiu population, the most valuable in Câmpina, ranks 2nd at Gurghiu and the Turda population (ranked first in Gurghiu) registered the highest value for the DBH also in the Avrig trial (Budeanu et al. 2012a). However, significant correlation between the populations of the two trials could not be detected (Figure 1).

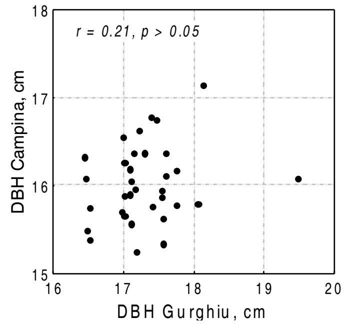

Figure 1. DBH of the populations for Gurghiu against Câmpina trials; r = correlation coefficient, p = significant level

While for the Câmpina experiment the six most valuable populations originate from the Curvature Carpathians (67%) and in the Southern Carpathians (33%), the most valuable populations in the Gurghiu test (placed in the Eastern Carpathians) originate mostly from the Eastern Carpathians (67%). Therefore the test established in the natural range of spruce confirms the higher value of the populations originating in the Eastern Carpathians, also proven by the Brežcu trial (Budeanu et al. 2012a), also located in the species optimum, in the transition area between the Curvature and the Eastern Carpathians.

The variance analysis (Table 2) in both trials resulted in non-insignificant differences between populations. However, in the Câmpina trial, the relatively heterogeneous conditions were reflected in the strongly significant differences ($p < 0.01$) between the three replications.

The influence of testing site was strongly significant in the Câmpina trial and the populations originated from different Carpathian branches performed differently in this trial but not in the other trial (Table 2).

In the joint analysis of the two trials the effect of locality on DBH and all other traits was strongly significant (Table 3). The group × locality effect was significant while the group effect on DBH was non-significant.

The population component of variance, for almost all of the analysed traits, except pruning height, was small. The interactions between individual trees (included in error) had much higher contributions to total variance (Figure 2).

In both experiments, the nearest provenances (19-Azuga at Câmpina, respectively 12-Gurghiu, at Gurghiu)

Table 2. Results from ANOVA for the diameter at breast height (DBH), tree slenderness coefficient (TSC), pruning height (PH), crown diameter (CD), crown slenderness index (CSI) and dominant branch diameter (DBD), of Norway spruce populations in two Romanian field trials. The Câmpina trial is located outside the natural range of Norway spruce

Trait	Source of variation	*DF*	Sum of squares	Mean square (s^2)	F_{value}	Sum of squares	Mean square (s^2)	F_{value}
			Field trial Campina			Field trial Gurghiu		
DBH	Replication	2	76.8	38.4	5.89**	11.6	5.8	0.75
	Population	35	212.0	6.1	0.93	369.4	10.6	1.38
	Groups	3	64.4	21.5	3.31*	45.9	15.3	2.0
	Error	1039	6730.1	6.5	-	7950.5	7.7	-
TSC	Replication	2	4682	2341	17.3***	2187	1094	14.6***
	Population	35	10016	286	2.1***	7059	202	2.7***
	Groups	3	2213	738	5.5**	506	169	2.3
	Error	1039	140078	135	-	77465	75	-
PH	Replication	2	1024.89	512.4	212***	526.22	263.11	175***
	Population	35	591.02	16.89	6.97***	407.73	11.65	7.8***
	Groups	3	40.28	13.43	5.55***	26.83	8.94	6.0***
	Error	1039	2515.85	2.42	-	1537.63	1.50	-
CD	Replication	2	15.61	7.8	37***	8.71	4.35	15.8***
	Population	35	19.09	0.55	2.58***	27.39	0.78	2.84***
	Groups	3	4.12	1.37	6.49***	3.00	1.00	3.6*
	Error	1039	219.31	0.21	-	284.38	0.27	-
CSI	Replication	2	17.17	8.58	20***	53.95	26.98	52***
	Population	35	57.52	1.64	3.87***	70.54	2.02	3.9***
	Groups	3	8.59	2.86	6.85***	9.39	3.13	6.0***
	Error	1039	433.93	0.42	-	528.73	0.52	-
DBD	Replication	2	3.706	1.853	14.1***	1.562	0.781	6.87**
	Population	35	17.840	0.51	3.9***	5.103	0.146	1.28
	Groups	3	7.445	2.482	18.9***	0.377	0.126	1.11
	Error	1039	136.09	0.131	-	118.2	0.114	-

DF – degrees of freedom, levels of significance: * – 0.05 > *p* > 0.01, ** – 0.001 > *p* < 0.01, ***– *p* < 0.001*, groups – Romanian Carpathians branches: Eastern Carpathians; Curvature Carpathians; Southern Carpathians; Western Romanian Carpathians

Table 3. ANOVA for the diameter at breast height (DBH), tree slenderness coefficient (TSC), pruning height (PH), crown slenderness index (CSI) and dominant branch diameter (DBD), of Norway spruce populations in two Romanian field trials. One trial is located outside the natural range of Norway spruce. Abbreviations of traits as in Table 2

Trait	Source of variation	*DF*	Sum of squares	Mean squares (s^2)	Trait	*DF*	Sum of squares	Mean squares (s^2)
DBH	Locality	1	846.4	846***	DBH 4 trials	3	13692	4564***
	Population	35	354.2	10.1		35	836	24**
	Group	3	52.7	17.6		3	22	7.3
	P × L	35	227.3	6.5		105	2145	20**
	G × L	3	57.6	19.2*		9	396	44*
	Error	2082	14769.0	7.1		4164	59682	14.3
TSC	Locality	1	30842	30842***	PH	1	20.7	20.7**
	Population	35	11039	315***		35	658.8	18.8***
	Group	3	1131	377*		3	28.4	9.5*
	P × L	35	6036	172*		35	340.0	9.7**
	G × L	3	1589	530**		3	38.7	12.9**
	Error	2082	225543	108		2082	5604.6	2.7
DBD	Locality	1	5.291	5.3***	CSI	1	54.4	54***
	Population	35	13.377	0.38***		35	71.22	2.03***
	Group	3	4.113	1.37***		3	9.1	3.03**
	P × L	35	9.567	0.27***		35	56.83	1.62***
	G × L	3	3.709	1.24***		3	8.88	2.96***
	Error	2082	259.56	0.125		2082	1033.77	0.50

DF – degrees of freedom, levels of significance: * – 0.05 > *p* > 0.01, ** – 0.001 > *p* < 0.01, ***– *p* < 0.001*, G × L – Groups × Localities interaction. For DBH data from four trials were included in the estimates, the additional data coming from Avrig and Breţcu (Budeanu et al. 2012a)

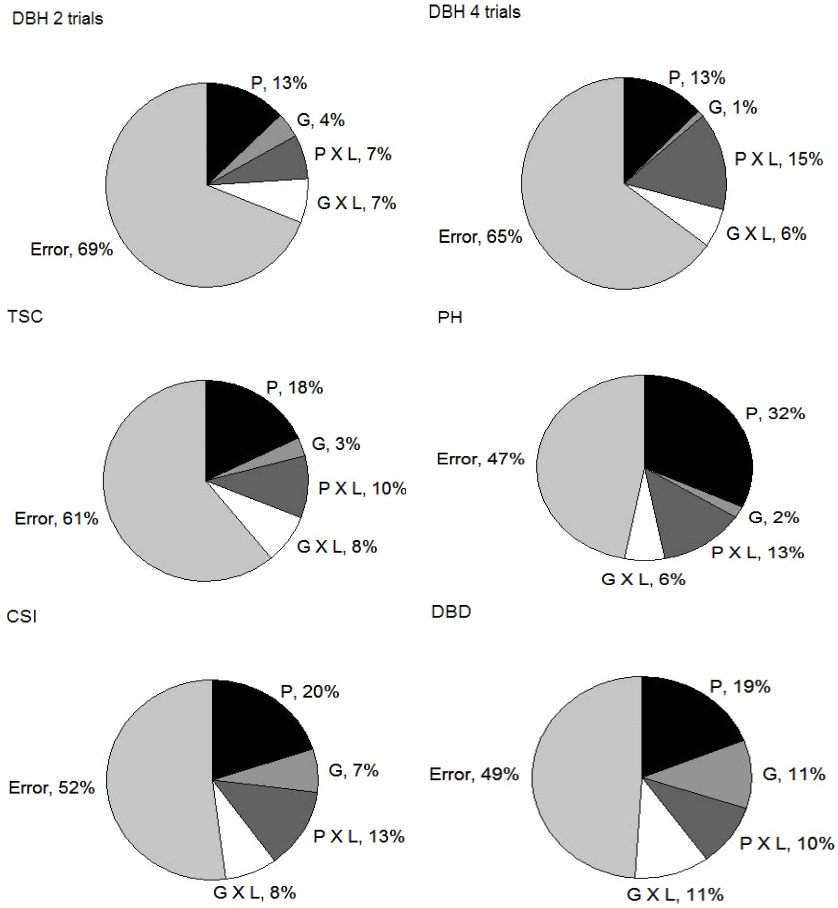

Figure 2. Variance components for populations × localities interaction P – populations, G – groups, and P × L, G × L are the interactions between random factors and Locality (fixed factor). DBH, PH, TSC, CSI, DBD are the variables with the significance described in Table 2

rank 4th in the classification achieved for this feature. The 5-Moldoviţa population, appointed as IUFRO standard progeny since 1996, ranks 11th in Câmpina, respectively 21st in Gurghiu, registering values very close to the average of the two tests.

The Q_{ST} value (Table 4) is 28% higher in the INR trial than in the other trial, suggesting higher variability among populations under favourable growth conditions. This conclusion is valid for most of the growth traits (except DBD). The DBH Q_{ST} values are lowest among all the traits analysed. The breeding programs should focus on selection based on other traits.

Cumulating these data with the ones from the Avrig and Breţcu trials, that are part of the same series of experiments (Budeanu et al. 2012a), a strong influence of the testing site was noted, but also a strong significant ($p < 0.01$) effect of the populations and populations × locality interaction was obtained.

Table 4. The quantitative genetic differentiation, Q_{ST}, according to Morgan et al. (2005). Abbreviations of traits as in Table 2

Trait	Q_{ST}		
	Câmpina	Gurghiu	Both trials
DBH	0.32	0.41	0.42
TSC	0.50	0.60	0.59
PH	0.80	0.80	0.78
CD	0.57	0.58	0.64
CSI	0.66	0.66	0.67
DBD	0.66	0.39	0.60

Tree slenderness coefficient (TSC)

This trait, expressed by the ratio of tree height and DBH is of particular importance in order to assess the stability of Norway spruce forests, estimating that a value of TSC higher than 80 could jeopardise the stability of stands against wind damage (Popa 2005). At 30 years of age and considering that no silviculturale treatments were carried out, TSC values up to 100 could be accepted.

In the Câmpina test (ONR), the average value of this indicator is 107.8, while it was 99 in the Gurghiu trial. In Câmpina, a single population (16-Nehoiu) has a TSC < 100, while in Gurghiu 63% of the populations have a TSC ≤ 100; the most valuable population being also this time 28-Turda (91), 13% under the highest value. These data confirm once more the risks occurring when planting spruce outside its natural range. In Gurghiu, grouping populations by Carpathian branches shows a slight superiority (1-2%) of the offspring's originating in the Western Carpathians, compared to the other Carpathian groups. In Gurghiu, the local population (12-Gurghiu) ranks 10th, while in Câmpina, the population closest to the experiment (19-Azuga) ranks 25th. The IUFRO standard population shows an average value lower by 9% INR, where the recorded value is ≤100.

ANOVA (Table 2) revealed strongly significant differences among populations, which enables improving programs at interpopulational level. Only in Câmpina trial significant differences were recorded between Carpathian divisions (groups), suggesting a different reaction to the adverse site condition existing at Câmpina. The factorial ANOVA (Table 3) showed a strongly significant effect for test site and populations. Of the two interactions the group × locality was strongest.

Pruning height (PH) and pruning height ratio (PHR)

In Câmpina trial (ONR) the pruning height (PH) is 7.9 m, while in Gurghiu (INR) the value is 4% higher (8.2 m). In both experiments, the highest capacity of achieving the natural pruning is shown by the 19-Azuga population, representing the population originated from the smallest distance from Câmpina trial, while in Gurghiu the local population (12-Gurghiu) ranks only 28th. The ratio of the pruning height to the total height (PHR) is 47% in Câmpina and 48% in Gurghiu, as the 19-Azuga population registered a value of 53% average of the two experiments. The IUFRO standard provenance (5-Moldovița) showed different results and a far better performance outside the natural range (PH = 8.5 m and PHR = 50%), where PH and PHR are 19%, and 16% higher than in the established INR test. Separating populations by the Carpathian branches showed an obvious superiority of the populations originating from Eastern Carpathians.

ANOVA (Table 2) and factorial ANOVA (Table 3) showed highly significant differences among populations and groups for pruning height, but also indicated strong interaction effects. For this trait the highest values of Q_{ST} were obtained in both trials, suggesting an important genetic control for natural pruning (Table 4).

Crown diameter (CD) and crown slenderness index (CSI)

Average value for CD is 3.26 m at Câmpina, while at Gurghiu the value is 5% lower, 3.1 m. It was noted an increasing trend of CD in the trial established ONR, in Subcarpathians, with negative consequences on the tolerance of trees to heavy snow. In Câmpina trial, amongst the 11 populations with the lowest values for crown diameter, 55% originated from Apuseni Mountains, an area known for the presence of the narrow crown spruce ideotype. The ANOVA (Table 2) revealed strongly significant differences between populations and between Carpathian divisions (***). The factorial ANOVA (Table 3) for CSI revealed strongly significant effects for all five effects tested. The "local" provenances have high values for CD in both experiments, occupying 5th place in Cāmpina trial, respectively 4th in Gurghiu trial. The standard provenance (5-Moldoviюa) had the same CD value (3.2 m) at both trials, very close to average values in the trials.

In Câmpina test, crown slenderness index (CSI) has an average value of 5.28, while at Gurghiu test, the value is 6% higher (5.6). In Câmpina test, except populations from the Curvature Carpathians, for all the other three Carpathian branches results are similar, while at Gurghiu test, populations originating from the Southern Carpathians stand out (Figure 3).

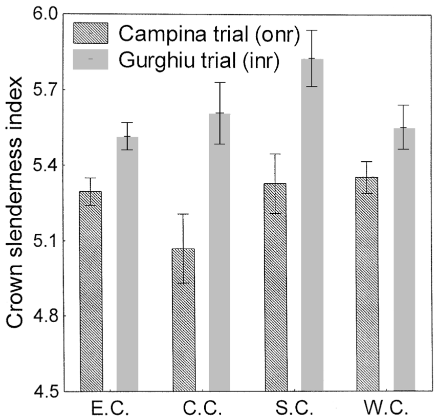

Figure 3. Mean values for crown slenderness in four regions of the Carpathian Mountains in Romania. E.C. – Eastern Carpathians; C.C. – Curvature Carpathians; S.C. – Sothern Carpathians; W.C. – Western Romanian Carpathians

In Câmpina, nearest provenance (19-Azuga) ranks 16th place, while in Gurghiu, the local provenance (12-Gurghiu) ranks 27th place. Standard provenance (5-Moldovița) has similar values in both experiments (5.5) and a favorable reaction in the ONR trial.

Dominant branch diameter (DBD) and branches finesse (BF)

In the Câmpina trial, the average value for the DBD is 19 mm, which represents 12.4% of the trunk diameter (diameter measured at 2.2 m from the ground). In the optimum of the species (Gurghiu), values are once again more favorable (DBD = 18 mm and BF = 10.8%), both in terms of resistance to the harmful action of heavy snow and in terms of quality wood (thin branches = smaller nodes). Populations 33-Gârda (Western Romanian Carpathians) and 1-Coșna (Eastern Carpathians), have thin branches in both experiments. Local provenances have high values for both traits, in both experiments, while the standard IUFRO provenance (5-Moldovița) has thin branches in both test sites.

Eastern and Western Carpathians populations showed superiority, while provenances originating from the Curvature Carpathians could provide forest reproductive materials for the installation of biomass crops, in local conditions similar to those in Câmpina. From figure 4 it is seen that there is a homogeneity of groups at the INR trial (Gurghiu), with a difference between groups being less than 2% for BF and 4% for DBD.

The variance analysis (Table 2) confirmed the high homogeneity of the Gurghiu test, while in Câmpina (ONR) we have noted very significant differences between populations and also between groups ($p < 0.001$). Factorial ANOVA (Table 3) for DBD indicated strongly significance for all effects tested. At the ONR test locality the populations originating from different Carpathian branches responded differently.

Correlations

In both experiments, although they were established in different environmental conditions, we noted obvious similarities in terms of correlations between analysed traits (Table 5). With increasing DBH pruning is intensified (positive correlation). At the same time, crowns have larger diameter and the branches are thicker (negative correlations for stand's stability and for wood quality). The more crown slenderness index increases, the thinner the branches (r = -0.30*** at Câmpina, -0.49*** at Gurghiu), which gives trees increased tolerance against abundant snow.

For most traits in both trials the influence of the geographical origin of the tested population was insignificant. Only for one trait (DBD) and only at the INR trial a significant influence of geographical origin was observed, populations from northeastern Romania (Eastern Carpathians) have thin branches. Also, in Table 5, it can be seen an opposite trend of geographical influence in both experiments, for most of the analysed traits. The influence of the populations origin altitude to the most important qualitative trait (PH) was also highlighted in Figure 5. When the populations are separated according to their Carpathian origin, the correlations with altitude are stronger and sometimes significant. The different reactions of the

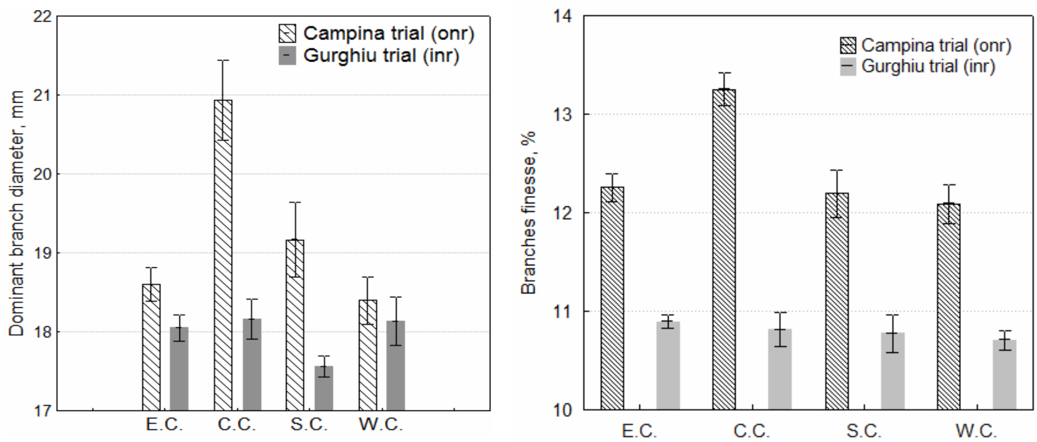

Figure 4. Mean values for dominant branch diameter and branch finesse in four regions of the Carpathian mountains in Romania. E.C. – Eastern Carpathians; C.C. – Curvature Carpathians; S.C. – Southern Carpathians; W.C. – Western Romanian Carpathians

Table 5. Pearson correlation coefficients between traits and between traits and geographic variables of population origin. Abbreviations of traits as in Table 2

Trait	DBH	TSC	PH	CD	CSI	DBD	DBH	TSC	PH	CD	CSI	DBD
	Câmpina trial						Gurghiu trial					
DBH	-	-0.83***	0.19***	0.65***	-0.24***	0.75***	-	-0.84***	0.20***	0.79***	-0.43***	0.83***
TSC		-	0.11**	-0.51***	0.41***	-0.61***		-	0.07*	-0.67***	0.56***	-0.70***
PH			-	0.09*	0.23***	0.09*			-	0.09*	0.17***	0.12***
CD				-	-0.79***	0.60***				-	-0.82***	0.76***
CSI					-	-0.30***					-	-0.49***
DBD						-						-
Lat. N	-0.31	0.13	0.18	-0.21	0.19	-0.44**	0.07	-0.32	-0.16	0.20	-0.29	0.11
C. Lat.	-0.25	0.08	0.01	-0.16	0.07	-0.29	0.13	-0.11	0.15	0.14	-0.06	0.02
Lon. E	0.20	-0.13	0.04	0.27	-0.16	0.35*	-0.11	-0.00	-0.27	0.05	-0.12	0.03
Altitude	-0.13	0.03	-0.06	-0.07	-0.01	-0.12	0.11	0.01	0.22	0.06	0.06	-0.03

Levels of significance: * – 0.05 > p > 0.01, ** – 0.001 > p < 0.01, ***– p < 0.001* populations from Southern Carpathians were recorded for the majority of traits.

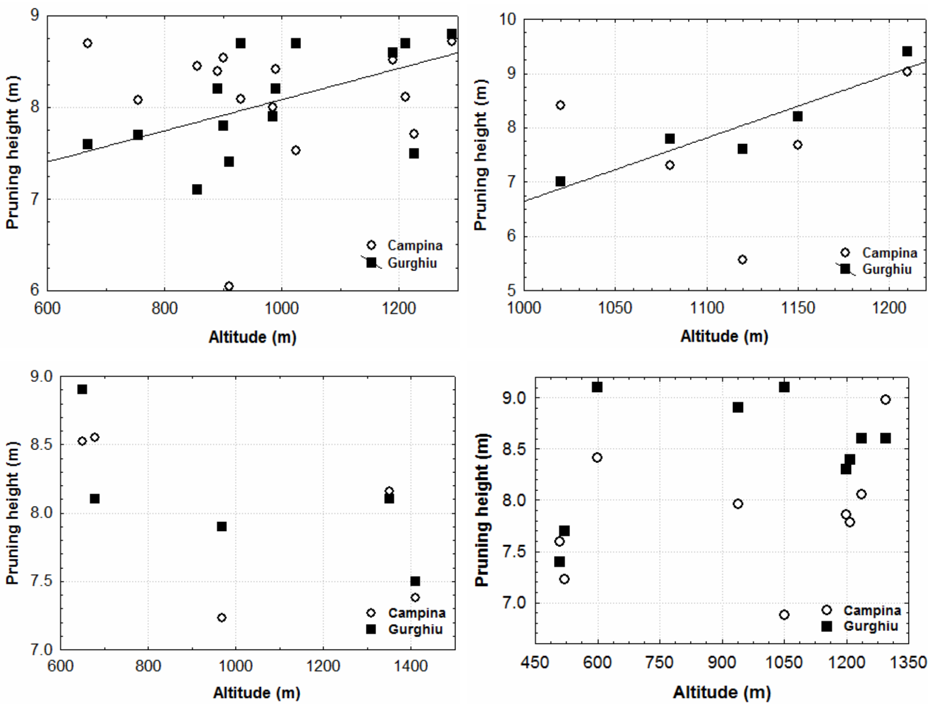

Figure 5. Correlation between pruning height and altitude of the population origin in the Câmpina and Gurghiu trials: upper left – Eastern Carpathian populations with significant r = 0.55* in the Gurghiu trial, upper right – Curvature Carpathian populations with significant r = 0.94* in the Gurghiu trial, lower left – Southern Carpathian populations, lower right – Western Romanian Carpathian populations

Discussion

The large number of populations and 6 × 6 tree plots require that the trials occupy large areas. Generally, this means that there will be a large heterogeneity within each trial. This is reflected in the large effect for replication in the present study. With the low number of replications and the strong replication effects the population effect might be underestimated in our study.

In the natural range of the spruce the pruning is more active, the DBH values are higher and the TSC indicates a higher resistance to the damaging wind action, compared to situation registered outside of the natural range.

With reference to previous data (Enescu and Ioniţă 2002) for DBH, available only for Gurghiu experiment, we found out that the local provenances (12-Gurghiu), the most valuable at the age of 15, remains at the top, now ranks 4, while population 1-Coşna, which presented the lowest value for this character, in the last 15 years had dropped to rank 23. The IUFRO standard provenance (5-Moldoviţa) recorded again higher values for DBH in the test located ONR, as previously noted (Budeanu et al. 2012a), which could represent a greater capacity to adapt to a longer growing season, but with much lower values for De Martonne index. This index is very important because it takes into account both the average temperature and the quantity of rainfall in a year.

The mean DBH value for the 4320 studied trees in the four experiments (Avrig and Breţcu too) is 18.3 cm, which is higher than the values recorded in Poland (14.2 cm, at the same age), Slovakia (13.2 cm, at 26 years old) and Germany (13.7 cm at 25 years old) by Matras (2009). In France (Loubère et al. 2004) were recorded the closest results (17.4 cm at 30 years old). By applying ANOVA, a similar result to that from Poland (Kowalczyk et al. 2009) was obtained, *i.e.* insignificant differences between populations.

In Norway, at the same age of 5 trials with full-sibs, TSC was 89 (Steffenrem et al. 2007), while in France, at the same age, TSC was 86 and 77 (Colin and Houllier 1992, Loubère et al. 2004), values that ensure higher stability of stands. Relatively low pruning height ratio values (compared with PHR = 50% in present study) were recorded in Sweden, at the same age (Norén and Persson 1997). The *crown diameter* and *crown slenderness* values indicate a plus of heavy snows vulnerability in the test located ONR.

The degradation of the Norway spruce in stands located outside its natural range as a result of low tolerance against harmful action of abiotic factors, was observed at ages 30-40 years in Ukraine (Guz 2009). At localities where there is no major risk for wind slashing, selection of the populations with high CD values can be applied, being known that the branches and the needles contribute up to 40% on the total biomass production (Kilpelainen et al. 2010), and the well-developed crowns provide a superior mast (White et al. 2007). Selection for the production of biomass could be practiced in similar site conditions as those of the test Câmpina.

The average values for *branches finesse* (BF) are superior to those previously determined by Budeanu et al. (2012b) (9.2% in Avrig test and 9.5% Brețcu test), but lower than those recorded at the same age in Finland and Sweden, where the average value is 12.7% (Mäkinen et al. 2003).

In both experiments positive correlations between DBH and DBD were obtained, in agreement with the results recorded in Germany (Hein et al. 2007). It can be concluded that for spruce the simultaneous breeding of quantitative and qualitative traits is contraindicated. The two-step breeding strategy suggested previously (Danusevicius and Lindgren 2002, White et al. 2007) might be useful to apply.

The populations 4-Marginea, 20-Domnești and 21-Orăștie, originated from the lowest altitude, had better rankings in ONR trial than in the INR trial. Other populations from low altitude (29-Beiuș and 30-Dobreşti) showed totally opposite behavior. The explanation could be related to the fact that the last two populations come from the ecological optimum of spruce (in Western Romanian Carpathians, in which the altitudinal limit for spruce is lower than in the other three Carpathian regions), while the first three come from a lower altitudinal limit.

Significant differences between populations suggests that there are good prospects for these populations to have a high potential for adaptation to future climates (Pliura and Eriksson 2002). However, extreme caution is required regarding the movement of forest reproductive materials. The genetic component seems to play the most important role in pruning. The different reaction capacity of spruce in multi-site comparative trials was also observed in other studies (Moberg 2006, Kantola et al. 2007, Barszcz et al. 2010).

The mainly weak relationships between traits and geographic origin is somewhat surprising considering a large difference in altitude among the populations, which in many other studies have resulted in strong relationships (e.g., Eriksson 2010). The most plausible explanation is that the climatic conditions in the area, from which the populations originated, do not follow any geographic trend.

Conclusions

For most of the analysed traits (except DBD), strongly significant differences between populations were recorded, which favors the ongoing selection programmes at the population level. The significant differences between Carpathian branches were recorded, with the largest differentiation in the Câmpina trial, suggesting a different reaction to the adverse site conditions existing outside the natural range of Norway spruce.

For all analysed traits, promising results were recorded in the trial situated in the optimum ecological conditions for Norway spruce (Gurghiu). Outside the natural distribution range (Câmpina), the populations presented high values for slenderness index, crown diameter and branches diameter, which increases the vulnerability of Norway spruce to the harmful action of abiotic factors such as wind or snow.

The populations originating from the Eastern Carpathians had a sustained growth, an active pruning and thinner branches. The IUFRO standard provenance (5-Moldovița) presented a high capacity to adapt to the site conditions from Câmpina test, which reiterates the great genetic value of this population.

In the majority of cases there was no significant relationship between geographic origin and trait values.

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References

Alexandrov, A. and Stankova, T. 1997. Norway spruce provenance trials in Bulgaria. IUFRO Norway spruce symposium, Stara Lesna, Slovakia, 8 pp.

ANM 2011. Romanian National Meteorological Administration.

Barszcz, A., Sandalak, A. and Sandalak, J. 2010. Knottiness of spruce stems from the Dolomites as the basis for distinguishing quality zones in round wood. *Folia Forestalia Polonica*, series A 52(2): 89-97.

Budeanu, M., Şofletea, N. and Pârnuţă, G. 2012a. Testing Romanian seed sources of Norway spruce (Picea abies): Results on growth traits and survival at age 30. *Annals of Forest Research* 55(1): 43-52.

Budeanu, M., Şofletea, N. and Pârnuţă, G. 2012b. Qualitative traits of Norway spruce [*Picea abies* (L.) Karst.] depending on first-order branches: evaluation in comparative trials. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 40(2): 295-301.

Colin, F. and Houlier, F. 1992. Branchiness of Norway spruce in northeastern France: predicting the main crown characteristics from usual tree measurements. *Annals of Forest Science* 49(5): 511-538.

Danusevicius, D. and Lindgren, D. 2002. Two-stage selection strategies in tree breeding considering gain, diversity, time and cost. *Forest Genetics* 9(2): 147-159.

Enescu, V. and Ionita, L. 2002. Inter and intra populations genetic variation of some Norway spruce (*Picea abies* (L.) Karst) forest genetic resources. *Annals of Forest Research* 45: 67-77.

Eriksson, G. 2010. Picea abies Recent Genetic Research. Swedish University of Agricultural Sciences, Dept Plant Biol. For. Gen. 192 pp.

Giertych, M. 1993. Breeding Norway spruce in Poland: from provenance tests to seed orchards. Norway spruce provenances and breeding. Proceedings of IUFRO (S2.2-11) Symposium, Latvia: 193-199.

Guz, M. 2009. Current state of *Picea abies* stands in the Ukrainian Carpathians. *Dendrobiology* 61(Supplement): 33-38.

Hein, S., Mäkinen, H., Yue C. and Kohnle, U. 2007. Modelling branch characteristics of Norway spruce from wide spacings in Germany. *Forest Ecology and Management* 242: 155-164.

Héois, B. and Van de Sype, H. 1991. Variabilité génétique de quinze provenances roumaines d'épicéa commun (*Picea abies* (L) Karst). Premiers résultats [Genetic variability of fifteen Romanian provenances of Norway spruce (*Picea abies* (L) Karst.). First results]. *Annals of Forest Science* 48: 179-192, (in French with English abstract)

Kantola, A., Mäkinen, H. and Makela, A. 2007. Stem form and branchiness of Norway spruce as a sawn timber – Predicted by a process based model. *Forest Ecology and Management* 241(1-3): 209-222.

Karlsson, B. and Hogberg, K.-A. 1998. Genotypic parameters and clone x site interaction in clone tests of Norway spruce (*Picea abies* (L.) Karst.). *Forest Genetics* 5(1): 21-30.

Kilpelainen, A., Routa, J., Peltola, H., Zubizarreta Gerendiain, A., Pulkkinen, P. and Kellomaki, S. 2010. Effects of genetic entry and competition on above ground biomass production of Norway spruce grown in southern Finland. *Forest Ecology and Management* 259: 2327-2332.

Kowalczyk, J., Markiewicz, P. and Matras, J. 2009. Intra-population variability of *Picea abies* from Zwierzyniec Lubelski and Bliżyn (Poland). *Dendrobiology* 61 (Supplement): 69-77.

Lines, R. 1967. Standardization of methods for provenances research and testing. XIV IUFRO Congress III: 672-719.

Loubère, M., Saint-André, L., Hervé, J.-C. and Vestøl, G.I. 2004. Relationships between stem size and branch basal diameter variability in Norway spruce (*Picea abies* (L.) Karsten) from two regions of France. *Annals of Forest Science* 61: 525-535.

Matras, J. 1997. Growth and plasticity of Norway spruce population in IUFRO 1972 experiment, IUFRO Norway spruce symposium, Stara Lesna, Slovakia, 12 pp.

Matras, J. 2009. Growth and development of Polish provenances of *Picea abies* in the IUFRO 1972 experiment. *Dendrobiology* 61(Supplement): 145-158.

Mäkinen, H., Ojansuu, R., Sairanen, P. and Yli-Kojola, H. 2003. Predicting branch characteristics of Norway spruce (*Picea abies* (L.) Karst.) from simple stand and tree measurements. *Forestry* 76(5): 525-546.

Moberg, L. 2006. Predicting knot properties of *Picea abies* and *Pinus sylvestris* from generic tree descriptors. *Scandinavian Journal of Forest Research* 21(S7): 49-62.

Morgan, T.J., Evans, M.A., Garland, T., Swallow, J.G. and Carter, P.A. 2005. Molecular and quantitative genetic divergence among populations of house mice with known evolutionary histories. *Heredity* 94: 518-525.

Naapola, M.L. 1997. The growth and adaptation of the IUFRO 1964/1968 Norway spruce provenance material in Finland. IUFRO Norway spruce Symposium, Stara Lesna, Slovakia, 17 pp.

Nanson, A. 2004. Génétique et amélioration des arbres forestières [Genetic and forest trees breeding]. Les presses agronomique de Gembloux, Belgium, 712 pp, (in French)

Norén, A. and Persson, A. 1997. Graded quality of 30-year-old Norway spruce grown on agricultural and forest land. *Studia Forestalia Suecica*, No. 203, Uppsala, Sweden.

Pliura, A. and Eriksson, G. 2002. Genetic variation in juvenile height and biomass of open-pollinated families of six *Castanea sativa* MILL. populations in a 2 x 2 factorial temperature x watering experiment. *Silvae Genetica* 51(4): 152-160.

Popa, I. 2005. Wind throw-risk factor in mountainous forest ecosystems. *Annals of Forest Research* 48: 3-28.

Skrøppa, T. 2005. *Ex situ* conservation methods. In: T. Geburek and J. Turok (Editors), Conservation and management of forest genetic resources in Europe. Arbora Publishers, Zvolen, p. 567–583.

Stakėnas, V., Žemaitis, P. and Ozolinčius, R. 2012. Crown conditions of Norway spruce in different eco-climatic regions of Lithuania: implications for future climate. *Baltic Forestry* 18(2): 187-195.

STATISTICA 8.0. 2008. StatSoft Inc., Tulsa, OK, USA.

Steffenrem, A., Saranpää, P., Lundqvist, S.-O. and Skrøppa, T. 2007. Variation in wood properties among five full-sib families of Norway spruce (*Picea abies*). *Annals of Forest Science* 64: 799-806.

Şofletea, N., Budeanu, M. and Pârnuţă, G. 2012. Provenance variation in radial increment and wood characteristics revealed by 30 years old Norway spruce comparative trials. *Silvae Genetica* 61(4-5): 170-178.

Ujvari, E. and Ujvari, F. 2006. Adaptation of progenies of a Norway spruce provenance test (IUFRO 64/68) to local environment. *Acta Silvatica Lignignaria Hungarica* 2: 47-56.

Viersma, J.H. 1962. Survey quantitative aspects of the exotic species. *Nederlands Bosbouw Tijdschrift* 34(5): 175-184.

White, T.W., Adams, W.T. and Neale, D.B. 2007. Forest genetics. CABI Publishing, Cambridge, 682 pp.

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МЕЖПОПУЛЯЦИОННАЯ ИЗМЕНЧИВОСТЬ КАЧЕСТВЕННЫХ ХАРАКТЕРИСТИК В ДВУХ ИСПЫТАТЕЛЬНЫХ КУЛЬТУР *PICEA ABIES* L. РАЗНЫХ ПРОИСХОЖДЕНИЙ

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Резюме

Потомство 33 лесосеменных заповедников эли оценивались 30 лет спустя после посадки, в двух испытательных культур, заложенных в различных условиях среды: за пределами естественного ареала, на малой высоте (Campina опыт), и в естественном ареале (Gurghiu опыт) в Румынии. Оценивались наиболее важные качественные и количественные характеристики роста ствола и кроны: диаметр ствола у 1,30 м, высота обрезки ветвей и пропорция обрезки и полного роста, отношение ширины к длине ствола, диаметр кроны и коэффициент стройности кроны, диаметр ветвей и его соотношение с диаметром ствола. В результате применения дисперсионного анализа обнаруживались существенные различий между популяциями по большинству проанализированы характеристик (кроме диаметра ствола). Значимые отклонения между Карпатскими ветвями были отмеченны для большинсво аннализированых характеристик, выше для Кэмпина компаративного опыта, что предпочитает различные реакции популяциях на боле неблагоприятные местные условия существовавшие в опытной площади которая находиться за пределы естесного ареала. По всем анализируемым характеристикам, популяции проявляли лучшие результаты, с точки зрения лесного хозяйства, на опытной площади расположенной в оптимальных экологических условиях для ели (Гургиу). За пределами естественного ареала (опыт Кэмпина), популяции проявляли высокие величины для отношении ширины к длине ствола, диаметр кроны и диаметр ветвей, то что повышает уязвимость ели к вредным действиям абиотических факторов (ветер и снег). Селекция ели одновременно для роста и качественных харахтеристик противопоказано. В этой ситуации рекомендуется двухэтапнная стратегия селекции. Высота обрезки ветвей показала наивысшие оценки Q_{ST}.

Ключевые слова: испытательные культуры, корреляции, диаметр ствола у 1,30 м, лесосеменные заповедники, харахтеритики ствола и кроны.