Available online at www.notulaebotanicae.ro

Print ISSN 0255-965X; Electronic 1842-4309

Not Bot Horti Agrobo, 2012, 40(2): 295-301

Notulae Botanicae Horti Agrobotanici Cluj-Napoca

Qualitative Traits of Norway Spruce [*Picea abies* (L.) Karst.] Depending on First-Order Branches: Evaluation in Comparative Trials

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Abstract

To establish the most important Norway spruce Romanian populations in order to improve the genetic value of future forests, open-pollinated progeny of ten plus trees originating from 33 Norway spruce seed sources were evaluated at the age of 30 years in two field trials established in different site conditions: outside (Avrig trial) versus natural range (Breţcu trial) of Norway spruce in Romania. Evaluations have been made concerning the most important branches characteristics, influencing wood quality: Number of branches per whorl, dominant branch insertion angle, dominant branch diameter and branch finesse. Highly significant differences ($p<0.001$) were found among seed sources in both sites for all of the analyzed traits. The strong populations × localities interaction show the high spruce ability to react to the changing environmental conditions. Near-sites populations were placed in the first half of ranking. Smaller values were recorded in the Avrig trial than in the Breţcu trial for the number of branches per whorl (4.5%) and branches finesse (5.1%). The populations from the Eastern Carpathians stand out by showing sustained growth and superior wood quality, while the populations from the Western Romanian Carpathians generally have smaller differences between the mean values of analysed traits in both field trials. Simultaneous improvement of the spruce following quantitative and qualitative traits pending on the number of branches per whorl and branches diameter is contraindicated. The two-stage selection strategy seems to be applicable in this case.

Keywords: branches characteristics, field trials, open-pollinated progeny, phenotypic correlations, seed sources, wood quality

Introduction

The Norway spruce is the main species spread in Europe's boreal and temperate regions (Korski *et al.*, 1997) so that, among conifers, it is the main resource for timber production in Europe (Lu *et al.*, 1995). In Romania, it is the predominant species within altitudes ranging from 1200 to 1800 m (Feurdean *et al.,* 2011).

In coniferous species, including Norway spruce, the wood quality is influenced by the first-order branches (Barszcz *et al.*, 2010). Therefore, the branches' thickness and their insertion angle largely influence the knots' size and their length in timbered wood, while the number of branches per whorl influences the number on knots from and between whorls. Compared with 90°, the higher or the lower the insertion angle is, the higher is its negative effect on timber (Meredieu *et al.*, 1998), as the knots' length increases. At the same time, the literature mentions the existence of a direct correlation between the acute angle branches' disposal and the knots' size (Raymond and Coterill, 1990 – in Isik and Isik, 1999). Perstorper *et al*. (2001) remarked that the timber with big knots often presents high values for longitudinal contraction. Concurrently, the knots' surface influences the wood density, but also the timbered products (Kliger *et al.*, 1995).

Considering the mentioned context, the ampleness of researches on qualitative characters determined by first-order branches has increased during last decades, in the following directions: (*1*) decision on the proper silvicultural measures in order to decrease wood defects (Mäkinen and Hein, 2006; Pape, 1999); (*2*) the making of simulation studies in order to gain knowledge on wood quality evolution in different environmental conditions or silvicultural measures (Colin and Houlier, 1992; Hein *et al.*, 2008; Kantola *et al.*, 2007; Moberg, 2006); (*3*) wood quality analysis in trials for determining the Norway spruce's reaction in different site conditions (Barszcz *et al.*, 2010; Vestøl *et al.*, 1999).

The present study analyzes four of the most qualitative branches characteristics in trials established for testing the phenotipical value of 33 Norway spruce seed stands from the Romanian Carpathians. The assessment was realized at the age of 30 in two trials: one within and the other outside the species' natural distribution range (Breţcu trial and respectively Avrig trial). The working hypothesis tackle: (*1*) the comparative analysis of the results registered in both trials; (*2*) the study of the behaviour of the populations originating in different Carpathian branches; (*3*) quantification of phenotypical value of local or nearest to testing site populations and of the population 5-Moldoviţa, designated as standard provenance by I.U.F.R.O (International Union of Forest Research Organizations).

Materials and methods

Plant material

The Avrig trial is located outside the Norway spruce natural range, in Southern Subcarpathians region, within the mountainous - pre mountainous beech stands vegetation layer. The altitude is 615 m, about 300 m below the inferior altitudinal limit of the Norway spruce's natural distribution in that area. The geographical coordinates of the testing site are: 45°39'36" N and 24°26'12" E. According to the mapping of the regions of provenances, the test is included in sub region C1 (Pârnuţă *et al.*, 2010). The mean annual temperature is 8.3°C while the mean annual precipitations are 680 mm (ANM, 2011). The Breţcu trial is placed within the species' natural distribution range, at the transition zone between the Eastern and the Curvature Carpathians, at an altitude of 1100 m, in the mountainous mixed stands vegetation level. The geographical coordinates of the testing site are 45°58'16" N and 26°24'12" E, within B1 provenance sub region (Pârnuţă *et al.*, 2010). The mean annual temperature is 4.8°C, and the value for mean annual precipitations is 830 mm (ANM, 2011).

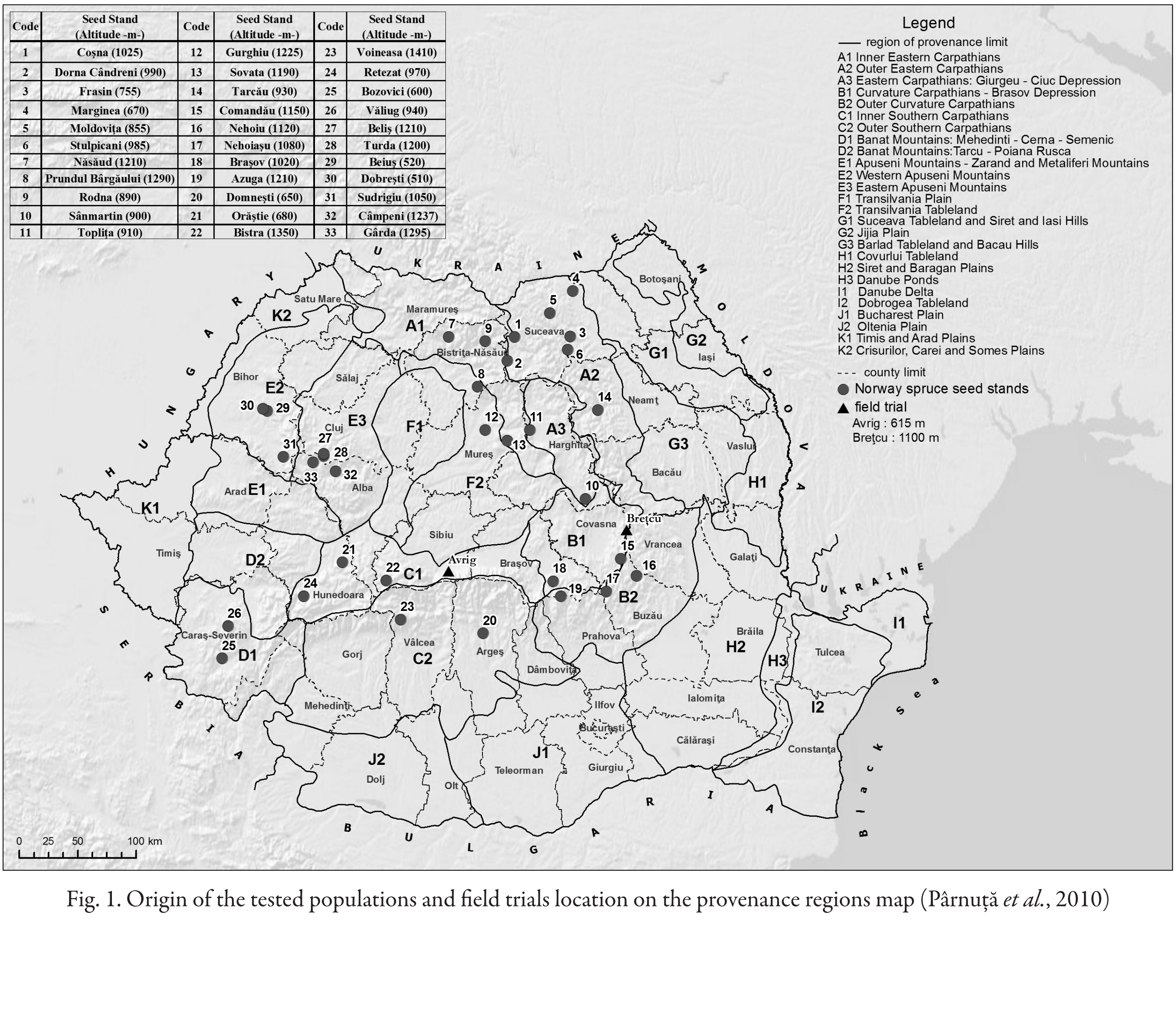
From each of the seed stands, 10 trees were selected by phenotypical criteria, separated by at least 50 m one from the other. The individuals tested in the two trials were obtained from the seed resulted by open pollination of the seed trees.

Experimental design and sampling

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 by 2 m spacing. Each population was represented by descendants obtained from bulked seeds harvested from 10 trees per population (Enescu and Ioniţă, 2002). The 33 seed stands (populations) were selected in order to have at least one high quality population from each region of provenance (Fig. 1).

Data analysis

According to I.U.F.R.O. guidelines (Lines, 1967), in each plot 10 descendants have been evaluated, totalizing 1080 measured trees in each trial, respectively 30 trees per population.



Code	Seed Stand (Altitude -m-)	Code	Seed Stand (Altitude -m-)	Code	Seed Stand (Altitude -m-)
1	Coşna (1025)	12	Gurghiu (1225)	23	Voineasa (1410)
2	Dorna Cândreni (990)	13	Sovata (1190)	24	Retezat (970)
3	Frasin (755)	14	Tarcău (930)	25	Bozovici (600)
4	Marginea (670)	15	Comandău (1150)	26	Văliug (940)
5	Moldoviţa (855)	16	Nehoiu (1120)	27	Beliş (1210)
6	Stulpicani (985)	17	Nehoiaşu (1080)	28	Turda (1200)
7	Năsăud (1210)	18	Braşov (1020)	29	Beiuş (520)
8	Prundul Bârgăului (1290)	19	Azuga (1210)	30	Dobreşti (510)
9	Rodna (890)	20	Domneşti (650)	31	Sudrigiu (1050)
10	Sânmartin (900)	21	Orăştie (680)	32	Câmpeni (1237)
11	Topliţa (910)	22	Bistra (1350)	33	Gârda (1295)

Fig. 1. Origin of the tested populations and field trials location on the provenance regions map (Pârnuţă *et al.*, 2010)

Three traits were measured or evaluated:

- number of branches per whorl (NBW) for the whorl at 2.20 m height or nearest to this (for ensuring the accessibility in the trials dead branches below 2.20 m were eliminated);

- dominant branch insertion angle (DBIA) of the whorl where NBW was evaluated. The following indices were used: 1 insertion angle lower than 90°; 2 insertion angle equal to 90°; 3 insertion angle higher than 90°;

- dominant branch diameter (DBD), measured with an electronic calliper.

The branch finesse (BF) = (DBD/D) × 100, where D represent the stem diameter under the 2.2 m whorl, was also determined.

The normal distribution was checked with the Kolmogorov - Smirnov test and Levene's test was used to assess variance homogeneity for applying ANOVA. The ANOVA was used to determine the variance components as a result of the populations and replications influence, and the residual variance as well. In accordance with the experimental design, the mathematical model used was the one recommended by Nanson (2004) and White *et al.* (2007):

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

where: m = overall average value, α_i = component of i populations (i = 1...a), β_j = component of j replications (j = 1...b), ε_{ij} = random error that influences ij plots.

After ANOVA applied to each trial, the results were cumulated and analyzed using a bi factorial analysis in order to highlight the influences of the testing site and that of the populations x localities interaction, according to the model recommended by Nanson (2004):

$X_{ijk}=m+\alpha_i+\beta_j+\alpha\beta_{ij}+\varepsilon_{ijk}$

where: m şi α_i have the same signification as mentioned above, β_j = component of j localities (j = 1......b), $\alpha\beta_{ij}$ = interaction of i populations with j localities, ε_{ijk} = random error.

The signification level was determined by using the Fisher (F) test and the test „t", for transgression possibilities of 5%, 1 % and 0.1%. The ranking of populations and their separation on homogenous groups was realized by using the Duncan test for a 5 % transgression possibility. The Pearson correlations between traits, and between traits and the ecological gradients of the tested seed stands' origin, were also determined.

The software used for data processing is composed of Statistica 8.0, Microsoft Office Excel and ArcGIS.

Results and discussion

Number of branches in whorl (NBW)

The average value in the Avrig trial was 6.4, which was 4.5% smaller than the average value recorded in the test placed in the natural habitat. Four of the first five populations with a small NBW originate from the Eastern Carpathians. Otherwise, this was the Carpathian branch with the lowest average NBW (6.3). The 22-Bistra, being the closest population placed near the Avrig trial, ranks 22, with an average of 6.5 branches.

In the test installed in the natural habitat (Breţcu), the average value of NBW was 6.7. The 15-Comandău local population was placed at the average level of the experiment. The lowest NBW is shown by offspring populations originating from the Curvature Carpathians (6.6 branches).

Running the Duncan test, a separation of the 33 populations in 8 homogeneous groups in Avrig and in 7 homogeneous groups in Breţcu came out, showing a high interpopulational variation for this trait, conclusion confirmed also by the AVOVA test (Tab. 1). Also, the test site has a very important influence in the final result. The fact that populations x localities interaction are very significant suggests a strong population response to changing environmental conditions (Tab. 1).

The 5-Moldoviţa source, catalogued as standard by I.U.F.R.O., has the same NBW in both trials (6.6) as the populations 4-Marginea and 29-Beiuş, indicating the high phenotipical stability of these populations. At the same time, only 5 populations (3 from Western Carpathians) show a higher NBW in the Breţcu test. This fact indicates a growth trend of the average NBW outside the natural range, leading to the quality decrease of spruce wood produced in such trials.

In relation to the NBW, the wood quality increases when the NBW decreases. Populations and trees with a reduced number of branches are also considered to be better adapted for areas with heavy snow, as they do not retain a big quantity of snow (Stănescu and Şofletea, 1998). On the other hand, populations showing high values of this trait and thick branches can be considered valuables for areas with no danger of windfall and snow, being of interest for an increased biomass production, because it is known that the branches and needles represent up to 40 % of the total biomass production (Kilpelainen *et al.*, 2010).

The decreasing NBW outside the natural habitat shows a certain reaction capacity of the Norway spruce to environmental changes, especially for the populations originating in the Eastern and the Curvature Carpathians. The assessments made in other areas of the Norway spruce habitat registered close values for this trait [6-7 branches in Sweden and Finland - Mäkinen *et al.* (2003); 6.3-7.4 branches in Norway, at the age of 7, in an offspring test *full sib* - Skrøppa (1996)] and the existence of a strong genetic control, under a relatively low influence of the environmental conditions may be inferred. On the other hand, the positive and highly significant correlations between the trees height and the NBW (0.36*** in Avrig and 0.19*** in Breţcu) comply with the data provided by Colin and Houlier (1992), according to whom the number of branches increases with the height of the coexisting trees. In this context, the conclusion drawn is that the simultaneous improvement of the spruce following quantitative

Tab. 1. ANOVA for the number of branches per whorl (NBW), dominant branch insertion angle (DBIA), dominant branch diameter (DBD) and branches finesse (BF)

Trait	Source of variation	D.F.	Sum of squares	Mean squares (s^2)	F_{value}	Sum of squares	Mean squares (s^2)	F_{value}
			Avrig trial			Brețcu trial		
NBW	Replication	2	23.21	11.6	-	66.3	33.15	-
	Population	35	71.30	2.04	3.27***	65.97	1.88	2.59***
	Error	1042	648.49	0.62	-	757.8	0.73	-
DBIA	Replication	2	1.135	0.568	-	0.07	0.036	-
	Population	35	11.585	0.331	2.63***	12.83	0.366	2.87***
	Error	1042	131.131	0.126	-	132.89	0.128	-
DBD	Replication	2	223.9	111.9	-	518.0	259.0	-
	Population	35	1162.9	33.2	1.85**	955.0	27.3	1.44*
	Error	1042	18666.4	17.9	-	19801.9	19.0	-
BF	Replication	2	0.00423	0.0021	-	0.01470	0.00735	-
	Population	35	0.01270	0.0004	2.73***	0.04044	0.00116	2.43***
	Error	1042	0.13827	0.0001	-	0.49586	0.00048	-

Factorial ANOVA cumulating dates for both sites

Trait	Source of variation	D.F.	Sum of squares	Mean squares (s^2)	Traits	Sum of squares	Mean squares (s^2)	D.F.
NBW	Locality	1	43.35	43.35***	DBIA	0.289	0.289	1
	Population	35	76.85	2.20***		14.416	0.412***	35
	Population x locality	35	60.42	1.73***		9.994	0.286***	35
	Error	2088	1495.80	0.72		265.233	0.127	2088
DBD	Locality	1	1475.1	1475.1***	BF	0.01436	0.01436***	1
	Population	35	890.9	25.5		0.03101	0.00089***	35
	Population x locality	35	1226.9	35.1**		0.02212	0.00063***	35
	Error	2088	39210.2	18.8		0.65306	0.00031	2088

D.F. = Degrees of freedom; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

and qualitative traits pending on the NBW in whorl is contraindicated. The two-stage selection strategy seems to be applicable in this case, being recommended for such situations in the specialized literature (Danusevicius and Lindgren, 2002; White *et al*., 2007).

Dominant branch insertion angle (DBIA)

In the Avrig test, the average value of the numerical index of quantification for this trait was 1.87 (equivalent to about 84°) and 7 of 33 seed sources included in the experiment registered an optimal value (90°). The closest native population to the testing place, 22-Bistra, registered a good result: an average numerical index of 1.97, representing an insertion angle of about 89°.

The DBIA in the natural habitat (Brețcu test) registers an average value of 1.84 (about 83°) and the local source (15-Comandău) also registers this time a higher outcome as compared to the experiment's average (numerical index 1.90, respectively about 86°).

The I.U.F.R.O. standard source (5-Moldovița) registers very good results in the Avrig trial (about 91°), unlike the Brețcu trial, where the dominant branches are arranged in an 84° angle. Such situations are also registered for other populations, indicating an existing interaction populations x localities, confirmed by the data in Tab. 1.

The average DBIA for the range of 33 tested seed sources in both sites is about 83-84°. Even if the average values of the comparative trials are close, the variance at interpopulational level is high, as shown in the ANOVA test (Tab. 1).

This trait was positively and very significant ($p < 0.001$) correlated to tree height (r = 0.19*** in the Avrig test, respectively r = 0.18*** in Brețcu test), so, there is a higher possibility for trees with active height growths to have the main branches arranged perpendicular to the trunk, increasing wood cutting quality. The direct correlation between this trait, on one hand, and the corrected latitude and altitude of the place origin of the tested seed sources on the other, was recorded only in the experiment situated outside the natural range of spruce, but with a low intensity (Tab. 2).

Measurements made in Finland and Sweden show a value of about 82° for this trait (Mäkinen *et al.*, 2003), lower by 2 % than the average value of the two tests included in the actual study. Large increases in diameter, a bigger number of thicker branches without modifications of the insertion angle were registered in an experiment conducted in Sweden, under optimizing culture condition by application of nutrients (Mäkinen *et al.*, 2001). This experiment, as well as the data of present paper, suggests the existence of genetic control for this trait. On the other hand, highly significant differences ($p < 0.001$) determined at interpopulational level (Tab. 1) indicate the possibility of improvement by individual and populational selection.

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

In the Avrig test the dominant branch has an average thickness of 17.3 mm, which represents 9.3% from the trunk diameter below its insertion. The closest population from the test site (22-Bistra) has a similar value to the mean of the respective trial. Regarding the branches finesse (BF) the most valuable populations are 12-Gurghiu (8.4%), 15-Comandău (8.6%) and 4-Marginea (8.6%). But they only occupy positions 11, 24 and 20 in the ranking according to the branches diameter. Consequently, the correct designation of Norway spruce wood quality is advisable to analyze the BF too, not only the DBD. Among the Carpathians divisions, the populations from Southern Carpathians had the thinner branches (16.6 mm), but with the biggest proportion from the trunk diameter (9.4%). Thin branches and with a small value of branch/trunk ratio were recorded in the populations from the Eastern Carpathians (DBD = 17.0 mm and BF = 9.1%) (Fig. 2).

In the Brețcu trial the dominant branch represents 9.8% of the trunk diameter (DBD = 18.9 mm), and the most valuable population (those with fine branches) was 5-Moldovița (DBD = 16.6 mm and BF = 8.6%). According to the branches thickness, the local provenance from the Brețcu test, namely 15-Comandău (18.3 mm) is placed on the seventh position, while by taking into consideration the branch/trunk ratio it is placed only on the 30th position (10.6%). Regarding the Carpathians' branches, the populations from the Eastern Carpathians had an average thickness of the dominant branch of 18.7 mm, which represents 9.6% of the trunk diameter, while at the opposite pole were the populations from Banatului Mountains (DBD = 19.8 mm and BF = 10.5%).

ANOVA (Tab. 1) indicated highly significant differences ($p < 0.001$) among populations in both experiments for branches finesse while for dominant branch diameter the most important influence came from the test site environmental conditions. In relation to the values achieved in the two trials for DBD, the most stable Carpathian division, once again, was the Western Carpathians (0.08), while the unstable was the Southern Carpathians branch (0.27). The I.U.F.R.O. provenance (5-Moldovița) had lower by 11% values for this trait in the trial situated in the natural distribution range of the species, as compared with the value resulted from the trial situated outside the natural range.

As shown in Tab. 2, the correlation between the breast height diameter and the thickness of the dominant branch is positive, intense and highly significant (r = 0.88*** in Avrig and r = 0.76*** in Brețcu, respectively). In general, however, the mean values determined in this paper for BF (9.3% in the Avrig test and 9.8% in the Brețcu test, respectively) are lower than those reported in northern Europe. Thereby, according to the data published by Mäkinen *et al.* (2003) for stands from Finland and Sweden, at the same age, BF was 12.7% (ratio obtained at 1.30 m height). If on large areas of Norway spruce distribution range it is generally presumed that BF values increase from South to North, for the 33 seed sources tested in the Carpathians the correlations with the ecological gradients of the place of origin (altitude and eco-physiological latitude) are negative and with very low intensity (Tab. 2). The negative correlation between the branch thickness and the survival rate determined in both trials (extremely significant in the Avrig test and significant in the Brețcu test) confirms the adaptive

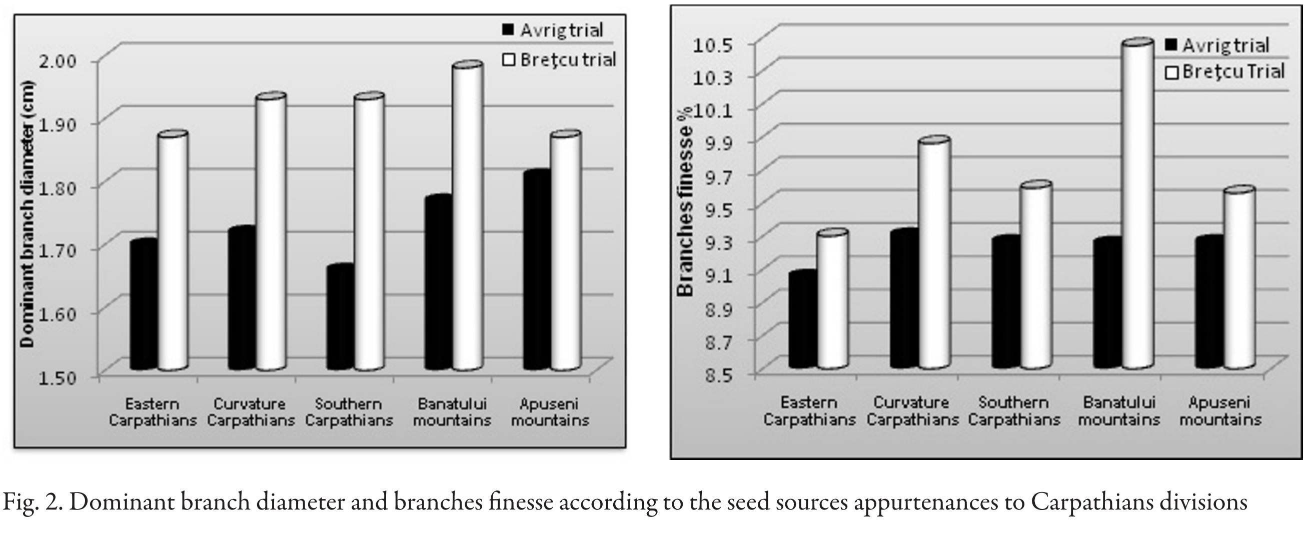


Fig. 2. Dominant branch diameter and branches finesse according to the seed sources appurtenances to Carpathians divisions

Tab. 2. Correlation coefficients matrix

Trait	NBW	DBIA	DBD	BF	Trait	NBW	DBIA	DBD	BF
	AVRIG trial					BREȚCU trial			
Number of branches in whorl	-	0.04	0.44***	0.06*	Number of branches in whorl	-	-0.01	0.19***	-0.07*
Dominant branch insertion angle		-	0.20***	-0.06*	Dominant branch insertion angle		-	0.13***	-0.12***
Dominant branch diameter			-	0.26***	Dominant branch diameter			-	0.22***
Branches finesse				-	Branches finesse				-
Total height	0.36***	0.19***	0.73***	-0.25***	Total height	0.19***	0.18***	0.63***	-0.26***
Breast height diameter	0.42***	0.23***	0.88***	-0.19***	Breast height diameter	0.23***	0.22***	0.76***	-0.26***
Survival rate	-0.03	-0.08*	-0.17***	0.05	Survival rate	-0.13***	-0.06*	-0.08*	0.04
Latitude (N)	-0.07*	0.03	0.01	-0.05	Latitude (N)	0.00	0.02	-0.06*	-0.10**
Ecophysiological latitude	-0.06*	0.10**	-0.03	-0.09*	Ecophysiological latitude	0.00	-0.04	-0.03	-0.05
Longitude (E)	-0.09*	0.00	-0.05	-0.05	Longitude (E)	-0.04	0.01	-0.03	-0.03
Altitude	-0.04	0.08*	-0.03	-0.07*	Altitude	0.00	-0.05	-0.01	-0.01

All correlations were established for 1080 trees/trial. * r = 0.06-0.09; ** r = 0.1-0.11; *** r > 0.12

value of branch thickness and is in agreement with previously published data in France (Loubère *et al.*, 2004). On another hand, in a clone trial from Sweden, Karlsson and Hogberg (1998) obtained a direct correlation between the branch thickness and the total height at the age of 6, but with a very low intensity (r = 0.07). In the two trials analyzed in this paper, between the branch thickness and the total height positive and high intensity correlations were registered, especially in the test from outside the spruce distribution range (r = 0.73 *** in Avrig and r = 0.63*** in Brețcu, respectively).

Conclusions

The strong populations × localities interaction show the high spruce ability to react to the changing environmental conditions, which implies caution in the movement of the forest reproductive material between regions with different environmental conditions.

For all the analyzed traits it was showed that the seed sources originating from the Eastern Carpathians, especially those located in the north, have a good potential for wood quality determined by the first-order branches. In general, local or near-sites populations were placed in the first half of ranking. They should further be an important source of forest reproductive material, supplementary balanced with performance allochthonous tested materials, produced by valuable populations.

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