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Provenance Variation in Radial Increment and Wood Characteristics Revealed by 30 Years Old Norway Spruce Comparative Trials

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Abstract

The performance of 33 Norway spruce [*Picea abies* (L.) Karst.] seed sources from the Romanian Carpathians was evaluated with respect to growth and wood characteristics in comparative trials located at two different site conditions: Avrîg- outside of the natural range of Norway spruce and Breţcu – within the natural range of this species. The radial increment (RI), latewood percentage (LWP) and conventional wood density (CWD) traits were evaluated at age 30 years after plantation. Phenotypic correlations between the evaluated traits, on the one hand, and between the same traits and the geographic gradients of the origin of seed sources, on the other hand, were calculated. Analysis of variance showed significant ($p < 0.01$) differences between seed sources for RI, while for LWP and CWD, the differences were highly significant ($p < 0.001$). These results suggest that selection at seed sources level could be possible. The test sites influence the LWP and CWD, while the RI is almost similar in both sites. For RI, the most valuable

populations are situated in the Eastern and Western Romanian Carpathians. The highest LWP was registered for the Eastern Carpathian populations, while the lowest was recorded for the Western Carpathian populations. The Southern Carpathian populations, characterized by a lower growth rate, had higher values for wood density.

Key words: *Picea abies*, radial increment, latewood, wood density, seed sources, comparative trials.

Introduction

Norway spruce [*Picea abies* (L.) Karst.], the most important coniferous species in Europe, covers about 1.48 million ha in Romania (INS, 2011), which represents 77% of the coniferous forests and approximately 23.3% of the entire forest area. The stands are either pure, especially at medium and high altitudes, or mixed with European beech, silver fir, and Norway spruce situated at low and medium altitudes in the Carpathian Mountains (ŞOFLETEA and CURTU, 2007). Norway spruce has also been the main species used for the afforestation of non-forest lands in the last decades (IORAŞ and ABRUDAN, 2006; DUTCĂ et al., 2010). In Romania, the Norway spruce genetic resources are mostly preserved *in situ*; 89 gene conservation units were established, representing approximately 20% of the total forest conservation sur-

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face (PĂRNUȚĂ et al., 2011). Moreover, *ex situ* conservation in seed orchards (78.5 ha) and comparative progeny and provenances trials (37.5 ha) have been carried out. Therefore, the two comparative trials analyzed in the present paper simultaneously fulfill the objectives of conservation and of testing the genetic variability of 33 Norway spruce seed sources from the Romanian Carpathians.

Provenance tests have expanded a lot since the beginning of the twentieth century under the auspices of the International Union of Forest Research Organizations (IUFRO), leading to experiments being performed with provenance from many countries. The most comprehensive compilation regarding the Norway spruce provenance tests was made by evaluating the spatial pattern of genetic variation (KONIG, 2005). There have been three different series of Norway spruce experiments under the coordination of the IUFRO, including Romania: 1938/1939, 1964/1968 and 1972. All the data published from the trials of Bulgaria, Hungary, Poland, Romania, Scotland, Finland, Sweden and Norway, among others, indicate that the eastern Romanian provenances (e.g. Marginea and Moldovița) are one of the most valuable for Europe with regard to growth traits and adaptability (MATRAS, 1977; GIERTYCH, 1984, 1993; ALEXANDROV and STANCOVA, 1997; NAAPOLA, 1997; KARLSSON and HOGBERG, 1998; SKROPPA, 2005; UJVARI and UJVARI, 2006; MIHAI, 2009).

The Avrig and Brețcu comparative trials belong to the multisite series of Romanian tests and were established in 1980. A phenotypic selection of the most valuable stands, designated as seed sources, in the natural area of the Norway spruce was first made, and then seed trees within the seed stand were selected during the establishments of these trials. The seedlings used germinated from open-pollinated seeds collected from seed trees. In these experimental trials, main objective was

to evaluate the genetic variation to achieve a good management strategy in order to ensure the use of improved forest reproductive materials. This can be done by selecting the most valuable seed sources in each region, which is evaluated by recurrent selection criteria and compatible with the environmental conditions in the afforestation areas (PĂRNUȚĂ et al., 2010). This is a highly important requirement mentioned in many studies of forest genetics (KRUTZSCH, 1992; WHITE et al., 2007). This stage of research makes possible the transition from the untested seed sources, where the genetic *status quo* of the populations is preserved (ENESCU, 1996), to the “tested” category of forest reproductive materials, which offers much more guarantees for creating valuable stands for quantitative, qualitative and adaptation traits.

The objectives of the study were (i) to assess the variability of economically important quantitative traits by evaluating 33 open-pollinated seed sources from two provenance trials, (ii) to compare the test sites with respect to studied traits, (iii) to test the traits if they are expressed differently in two trial sites, and (iv) to analyze the correlations between traits and the influence of the ecological gradients.

Materials and Methods

Two comparative trials were established using seedlings obtained from bulked seeds harvested from 10 seed trees (ENESCU, 1996) identified in each of the 33 seed sources presented in Table 1. The seed sources will hereafter also be referred to as populations, indicating the local populations providing the forest reproductive materials.

The Avrig trial is located outside the Norway spruce's natural distribution range in the Romanian Carpathians, at an average altitude of 615 m, 45°39'36" N lati-

Table 1. – Location and geographical coordinates of the tested populations (seed sources).

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	Coșna (A2)	1025/47°28'/25°10'	18	Brașov (B1)	1020/45°35'/25°35'
2	Dorna Candreni (A2)	990/47°17'/25°05'	19	Azuga (B2)	1210/45°28'/25°40'
3	Frasin (A2)	755/47°28'/25°48'	20	Domnești (C2)	650/45°11'/24°49'
4	Marginea (A2)	670/47°49'/25°50'	21	Orăștie (C1)	680/45°43'/23°16'
5	Moldovița (A2)	855/47°39'/25°34'	22	Bistra (C1)	1350/45°35'/23°45'
6	Stulpicani (A2)	985/47°22'/25°46'	23	Voineasa (C2)	1410/45°17'/23°55'
7	Nășăud (A1)	1210/47°28'/24°25'	24	Retezat (C1)	970/45°27'/22°51'
8	Prundul Bârgăului (A1)	1290/47°05'/24°45'	25	Bozovici (D1)	600/44°57'/21°59'
9	Rodna (A1)	890/47°26'/24°50'	26	Văliug (D1)	940/45°12'/22°02'
10	Sânmartin (A3)	900/46°13'/25°57'	27	Beliș (E3)	1210/46°32'/23°02'
11	Toplița (A3)	910/46°45'/25°20'	28	Turda (E3)	1200/46°33'/23°02'
12	Gurghiu (A1)	1225/46°45'/24°50'	29	Beiuș (E2)	520/46°52'/22°23'
13	Sovata (A1)	1190/46°40'/25°05'	30	Dobrești (E2)	510/46°53'/22°20'
14	Tarcău (A2)	930/46°54'/26°06'	31	Sudrigiu (E2)	1050/46°31'/22°35'
15	Comandău (B1)	1150/45°45'/26°20'	32	Câmpeni (E3)	1237/46°25'/23°10'
16	Nehoiu (B2)	1120/45°37'/26°30'	33	Gârda (E3)	1295/46°29'/22°55'
17	Nehoiășu (B2)	1080/45°30'/26°10'			

* Region of provenance established in Romania (PĂRNUȚĂ et al., 2010): A–Eastern Carpathians; B–Curved Carpathians; C–Southern Carpathians; D–Banat Mountains; E–Apuseni Mountains; D+E=Western Carpathians.

tude and 24°26'12" E longitude. The Brețcu trial was established in the ecologically optimum range of the species at an average altitude of 1000 m, 45°58'16" N latitude and 26°24'12" E longitude. In both comparative trials, the experimental design was a 6 x 6 incompletely balanced square grid design, with 3 replications and 49 seedlings per plot planted at 2 by 2 m spacing (Figure 1).

In each trial, 9 trees from each population (3 from every replication, belonging to the replication's mean diameter category) were chosen. The increment cores from these trees with Pressler borer were obtained at breast height (1.30 m), on the contour line for the Brețcu trial, where the land is slightly tilted, and along the north-south direction in the Avrig trial, where the land is relatively flat. The following characteristics were evaluated: (i) the annual radial increments, their mean value and coefficient of variation; (ii) the periodical average increment that occurred every 5 years; (iii) the width of the earlywood and latewood and their average values; (iv) the percentage of latewood from the width of

the annual rings; (v) the percentage of latewood from the periodical average increment that occurred every 5 years; and (vi) conventional wood density.

To measure radial growth and the values of earlywood and latewood, a Rinntech LINTAB 5 tree-ring measurement station was used, while recordings and initial data processing were made using the TSAP Win software. This software facilitates the simultaneous recording of earlywood and latewood radial increments. The constructive features of the device allow core measurement with a standard resolution of 1:100, using a Leica stereomicroscope that provides an enlargement factor of 6:1 (BADEA, 2008).

To determine conventional wood density (ρ_c), a method recommended by DUMITRIU-TĂȚĂRANU et al. (1983) was used:

$$\rho_c = \rho_0 \frac{100}{100 + \beta_v},$$

where ρ_0 is the density of anhydrous wood,

$$\rho_0 = \frac{\rho_{10\%}}{1.1 - 0.84 * \rho_{10\%}}; \rho_{10\%}$$

is the wood density determined at momentary humidity (which is the average humidity for the increment core extracted from 10 trees uniformly assigned in each comparative trial) and β_v is the total volume expansion of the increment cores: $\beta_v = 28 * \rho_0$.

The diameter and the length of the increment cores were measured with the Lintab 5 tree-ring measurement station. The weights were determined using an electronic scale with a 0.01-mg precision.

The data obtained for all the evaluated quantitative features were statistically processed using the STATISTICA version 8.0 software (StatSoft Inc., 2008). The normal distribution was checked with the Kolmogorov-Smirnov test and Levene's test was used to assess variance homogeneity before applying the Analyses of Variance (ANOVA). The total variance of the analysed traits was separated (NANSON, 2004) into variance components due to trial sites, replication in sites, populations (seed sources) in replications and the (residual) error variance. The variance component analyses and test of components were made according to the statistical model given below:

$$X_{ijk} = m + \alpha_i + \beta_{i(j)} + \gamma_{j(k)} + \alpha\gamma_{ik} + \varepsilon_{ijk}$$

where:

m = overall average trait value;

α_i = the effects of i sites ($i = 1...a$);

$\beta_{i(j)}$ = the effects of j replications in i sites ($j = 1...b$);

$\gamma_{j(k)}$ = the effects of k populations in j replications ($k = 1...c$);

$\alpha\gamma_{ik}$ = the effects of interaction between trial sites and populations (seed sources);

ε_{ij} = the random error.

The analysis of variance is adequate for these types of experiments because the traits are normally distributed and the trees belong to the same generation (WHITE et al., 2007).

Figure 1. – Field arrangement of populations in both comparative trials.

Legend: 1,2...33=Populations; x x x=trees in populations (49 bulked descendants in each population) planted at 2x2 m. 6 rows and 6 columns in each replications (experimental design: 6x6).

The level of significance of differences was established with the *Fisher's* (F) test and with the *multiple t-test* with $p < 0.05$. Population ranking and their homogeneous groups were determined with the *Duncan's* test at $p < 0.05$.

The Pearson phenotypic correlations between the traits, on the one hand and between these and the geographic gradients (including the ecophysiological latitude) of the seed source origins, on the other hand, were calculated. The ecophysiological latitude (VIERSMA, 1962) was estimated using the formula $Le = L + A/100$, where: Le = ecophysiological latitude; L and A = latitude and altitude, respectively. The latitude is then corrected for altitude in such way that 100 m difference in altitude is considered to equal a difference of one degree in latitude (BLADA and POPESCU, 2007).

Results

Radial increment (RI)

In the Avrig trial, the average value for RI was 4.053 mm/year. The largest radial increment was registered in the 5-Moldovița population (4.533 mm/year), followed by 32-Câmpeni (4.407 mm/year) and 10-Sânmartin (4.395 mm/year). The lowest RI value was recorded in the 16-Nehoiu population (3.660 mm/year), 17-Nehoiășu (3.733 mm/year) and 14-Tarcău (3.764 mm/year). Compared to the general average of the experiment, the 5-Moldovița seed stand had a 12% higher increase, while the value obtained in the 16-Nehoiu population was about 11% below the average. In this comparative trial, the majority of the seed sources tested presented a larger RI than the averages of the trial originating in the Western Carpathians (42.9%) and Eastern Carpathians (35.7%). The population 22-Bistra, originating from the Southern Carpathians and closest to the testing site, ranked as the 6th best performing seed source tested in this location with respect to radial increment.

In the Brețcu trial, the average RI was 4.104 mm/year. The largest radial increment was registered in 4-Marginea (4.647 mm/year), followed by 27-Beliș (4.362 mm/year) and 8-Prundul Bârgăului (4.346 mm/year). The lowest increment values were registered in 14-Tarcău (3.799 mm/year), 13-Sovata (3.805 mm/year) and 25-Bozovici (3.872 mm/year). The 4-Marginea seed stand achieved a 13% higher value compared to the average, while the 14-Tarcău population had a 7% deficit. From the tested seed sources, the ones with RI values above the general average of the trial came mainly from the Eastern Carpathians (55%), followed by the Western Carpathians (25%). The population 15-Comandău, which was situated closest to the testing site, only ranked at 10th position for the size of the radial increment in Brețcu. Another population in close proximity to the testing spot, 10-Sânmartin, was situated in the middle of the ranking, at 16th place.

The analysis of variance (Table 2) highlights significant differences ($p < 0.01$) among the studied populations, while no significant differences between the test sites were found. Likewise, very important interpopula-

Table 2. – ANOVA for radial increment and wood characteristics of Norway spruce seed sources over trial sites.

Source of variance	Sum of squares	DF	Mean square (s ²)	F _{value}	p
Radial increment					
Trial site	0.58	1	0.58	2.18	0.1405
Replication	5.21	2	2.61	9.8***	0.0001
Seed source	15.66	35	0.45	1.69**	0.0092
Trial site x seed source	9.83	35	0.28	1.06	0.4373
Error	152.03	574	0.265		
Latewood percentage					
Trial site	30769.9	1	30769.9	631**	0.0000
Replication	3797.0	2	1898.5	39***	0.0000
Seed source	3769.1	35	107.7	2.21***	0.0001
Trial site x seed source	2764.8	35	79.0	1.68*	0.0442
Error	26916.97	574	46.89		
Wood density					
Trial site	0.0578	1	0.058	127***	0.0000
Replication	0.0022	2	0.001	2.4	0.0908
Seed source	0.0344	35	0.001	2.17***	0.0002
Trial site x seed source	0.0158	35	0.0005	1.0	0.4863
Error	0.2604	574	0.0005		

DF = Degrees of freedom. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

tional differences ($p < 0.05$) resulted applying ANOVA for every 5 years periodical RI, excepting the 2006–2010 interval.

The Duncan's test with $p < 0.05$ revealed five homogeneous groups for the populations tested in Avrig, and only two groups in Brețcu. All the populations included in the most valuable homogeneous group displayed RI values above the average of the experiment.

The analysis of the radial increment coefficient of variation at the tree level and then as the population average allowed the identification of some populations whose radial increments were relatively uniform. We expected to identify such populations in the Eastern Carpathians, which is considered to be the optimal area for the Carpathian race of Norway spruce (STĂNESCU et al., 1997). This was confirmed in Brețcu, where the most steady increment rhythm was accomplished by populations 8-Prundul Bârgăului and 4-Marginea ($s\% = 36\%$), closely followed by 5-Moldovița ($s\% = 37\%$), 7-Năsăud and 12-Gurghiu ($s\% = 39\%$). The highest variations for radial increments from one year to another was observed for 23-Voineasa ($s\% = 55\%$), which came from the highest altitude (1400 m) and originating from the Southern Carpathians. Outside of the natural area for Norway spruce, in Avrig, populations with the smallest coefficients of variation of annual radial increments originated from various Carpathian areas: Southern Carpathians (24-Retezat, $s\% = 36\%$), Western Carpathians (25-Bozovici, $s\% = 44\%$) or Eastern Carpathians (1-Coșna, $s\% = 44\%$). In this trial, the highest values of the coefficients of variation of annual radial increments had some populations originating from Eastern and

Western Carpathians (10-Sânmartin and 16-Nehoiu, $s\%=57\%$, followed by 17-Nehoiășu, 19-Azuga and 27-Beliș, all of them with $s\%=55\%$).

Latewood percentage (LWP)

Latewood favorably influences certain properties of wood and wood products, as well as cellulose paste (DUMITRIU-TĂȚĂRANU et al., 1983).

In Avrîg, latewood represented an average of 24% of the total radial increment, having a rather large amplitude of variation, from 31.1% (5-Moldovița) to 16.8% (30-Dobrești). Besides the population 5-Moldovița, the 6-Stulpicani (30.3%) and 17-Nehoiășu (28.5%) populations also belonged to the first class of variation, all originating from the Eastern and Curvature Carpathians. The populations with the lowest proportion of latewood (30-Dobrești, 16.8% and 28-Turda, 17.9%) originated from the Western Carpathians.

In Brețcu, latewood represented an average of 38% of the mean value of RI. Similar to Avrîg, the highest percentage of latewood was recorded in the populations of the Eastern Carpathians (6-Stulpicani, 43.1%, 7-Năsăud, 42.2% and 5-Moldovița, 42.1%), and the lowest in those from the Western Carpathians (32-Câmpeni, 30.6%, 31-Sudrigiu, 31.8% and 30-Dobrești, 34.0%).

The ANOVA test (Table 2) indicated the existence of highly significant differences ($p<0.001$) among the populations, and between test sites and replications, which suggest a very important environmental influence and an important genetic influence. The significant value ($p<0.05$) for locations x populations interaction suggests that several populations may score an increase or decrease of the latewood percentage from one location to another. By applying Duncan's test with $p<0.05$, we observed a large number of homogeneous groups of populations (six in Avrîg and eight in Brețcu).

In both sites, the provenances with the closest origin to the test site were situated in the bottom half of the ranking: 20th position in Avrîg for 22-Bistra, and positions 17 and 22 in Brețcu for 15-Comandau and 10-Sânmartin, respectively.

Review of the latewood dynamics for every 5-year interval allowed the formulation of the following findings:

In Avrîg, the population 5-Moldovița (Eastern Carpathians), designated in 1996 by I.U.F.R.O. as a standard provenance, presented the highest latewood percentage in 4 out of 5 periods, excepting the interval 1996–2000, when it was ranked 3rd out of the 33 tested seed sources. In Brețcu, the population 4-Marginea (Eastern Carpathians), whose genetic value was demonstrated in international studies (UJVARI and UJVARI, 2006), occupied first place in 3 out of 5 periods (the interval 1986–2000) and second place in the 1991–1995 period for the latewood percentage. In both trials other seed sources with high latewood percentages in all the 5-year periods also originated from the Eastern Carpathians (eg 8-Prundul Bârgăului and 6-Stulpicani) and with low latewood percentages at each 5-year period originated from Western Carpathian (eg. 28-Turda, 29-Beiuș and 30-Dobrești, 32-Câmpeni, 31-Sudrigiu).

Conventional wood density (CWD)

In Avrîg, the average value of CWD was 0.348 g/cm³. The amplitude of variation among the average values of the tested populations was low, only 0.039 g/cm³; therefore, the value of the coefficient of variation was also very low (2.87%). The following populations were placed in the first class of values with the highest wood density: 11-Toplița (0.366 g/cm³), 24-Retezat (0.363 g/cm³), as well as 22-Bistra, 17-Nehoiășu and 16-Nehoiu (each with 0.359 g/cm³). The lowest value was found in 5-Moldovița (0.327 g/cm³), followed by 12-Gurghiu (0.329 g/cm³) and 32-Câmpeni (0.335 g/cm³). Applying the t multiple test resulted significant differences ($p<0.05$) between the populations from the top and bottom of the ranking, mentioned above. The populations with high radial increments had, as expected, low values of conventional density. The lowest value found in the 5-Moldovița population, which registered the largest radial increments in this comparative trial, was persuasive in this sense. There was a difference of 5 to 6% among the populations situated at the extremes of the ranking and the experiment average. The local origin (22-Bistra) was ranked 3rd in Avrîg.

In Brețcu, the average value of CWD was 0.329 g/cm³, 5.8% lower than the average value in Avrîg. By comparing the populational averages, there was also a low amplitude of variation, only 0.036 g/cm³, so the coefficient of variation had a similar value to the one determined in Brețcu (2.74%). The populations with the highest values for wood density were: 17-Nehoiășu (0.350 g/cm³), 24-Retezat (0.341 g/cm³) and 29-Beiuș and 14-Tarcău (both with 0.340 g/cm³). At the opposite end were 12-Gurghiu, 9-Rodna and 31-Sudrigiu, each with 0.314 g/cm³. A relationship between the density and the size of radial increment was also noticed in this trial. For example, 14-Tarcău ranked last according to the radial increments, but ranked third in decreasing order according to the conventional density. The populations closest to the testing site, 15-Comandău and 10-Sânmartin, displayed density values similar to the experiment average, placing themselves in the most valuable homogeneous group.

Highly significant differences among populations and between test sites (Table 2) were recorded. The populations x site interaction was no significant suggesting that the populations show stable performances across the test sites.

Correlation analysis

The RI was positively and highly significantly correlated with earlywood ($r=0.75^{***}$ in Avrîg, $r=0.68^{***}$ in Brețcu) and latewood ($r=0.44^{***}$ in Avrîg, $r=0.66^{***}$ in Brețcu), and negatively and highly significantly with wood density ($r=-0.21^{***}$ in Avrîg, $r=-0.33^{***}$ in Brețcu) – Table 3.

Regarding the interdependence between the width of annual rings and the ecological gradients of the stand's origins, there was a direct and significant correlation with latitude only in Brețcu, but not confirmed in Avrîg trial.

In Brețcu, the amount of latewood correlated highly significant with latitude ($r=0.20^{***}$), clearly signifi-

Table 3. – Phenotypic correlations between radial increment, wood characteristics and geographic gradients of the Norway spruce seed sources origin.

Variables	Earlywood	Latewood	Latewood percentage	Wood density	Latitude (N)	Ecophysiological latitude	Longitude (E)	Altitude
Comparative trial AVRIG								
Radial increment	0.75***	0.44***	0.07	-0.21***	0.00	0.01	-0.1	0.01
Earlywood	-	-0.27***	-0.60***	-0.28***	-0.02	-0.04	-0.20***	-0.04
Latewood		-	0.92***	0.08	0.03	0.07	0.13*	0.06
Latewood percent			-	0.17**	0.02	0.08	0.19**	0.07
Wood density				-	-0.12*	-0.07	0.06	-0.02
Comparative trial BREȚCU								
Radial increment	0.68***	0.66***	0.20***	-0.33***	0.14*	0.05	0.04	-0.01
Earlywood	-	-0.10	-0.60***	-0.37***	-0.03	-0.02	-0.10	0.00
Latewood		-	0.80***	-0.07	0.23***	0.09	0.16**	-0.01
Latewood percent			-	0.13*	0.20***	0.08	0.17**	0.00
Wood density				-	-0.12*	-0.14*	0.03	-0.09

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

cantly with longitude ($r = 0.17^{**}$) and not significant with ecophysiological latitude ($r = 0.08$), which explains the differences recorded between populations from different regions of study area. Thus, in both locations, the highest values were recorded in seed sources originating from the Eastern Carpathians, while the lowest values were from those in the Western Carpathians, in their northern branch represented by the Apuseni Mountains. However, in the trial outside the natural range, LWP did not reveal any correlation with latitude or ecophysiological latitude. Unlike latewood, spring increments were influenced mostly by longitude, the values decreasing from west to east. However, an influence of longitude ($r = -0.20^{***}$) was recorded only in the area located outside the natural range of Norway spruce. As expected, in both sites earlywood is negatively correlated with the wood density, but with a slightly higher intensity in the test installed in the natural range ($r = -0.28^{***}$ in Avrigh, and $r = -0.37^{***}$ in Brețcu). On the other hand, in Brețcu, the proportion of latewood positively and highly significant correlated with latitude and clearly significant with longitude. In Avrigh, the correlation was also positive, but the significance level was lower for latitude, while for longitude correlation was also clearly significant.

The correlations between CWD and latitude or ecophysiological latitude are negative but in very low intensity (Table 3). Therefore, they cannot be used as selection criteria for identifying valuable seed sources. This correlation type was also reported in other works conducted in spruce in Romania (STĂNESCU et al., 1997).

Discussion

The preponderance of populations with RI values higher than the overall average originating from the

Eastern and Western Carpathians confirm the superiority of their gene pool compared to those from the Southern Carpathians. This has also been observed in other studies done in comparative trials in Romania (ENESCU and IONIȚĂ, 2002; MIHAI, 2009).

The dynamics of RI values was similar for all populations. The highest one was recorded around the age of 10 to 15 years. Compared to the average RI for the 30 years of tests, the maximum periodic average increment for a 5-year interval was 45% higher in Avrigh and 42% in Brețcu. Populations from the Eastern and Western Carpathians were in the top of the rankings, while those from the Southern Carpathians showed a lower growing rate. Moreover, certain populations (*i.e.*, 4-Marginea and 5-Moldovița) displayed a higher increment during all the analyzed 5-year periods. However, other populations yielded lower RI values for the first periods, but this increased in the last decade (*i.e.*, 24-Retezat). A strong decrease of RI was recorded in the last decades for some populations (*e.g.* 10-Sânmartin in Avrigh and 23-Voineasa and 14-Tarcău in Brețcu). Such situations of periodical fluctuations in RIs can modify the population ranking established at a certain moment. For this reason, to get more conclusive data, research should continue in these comparative trials after 30 years of age. However, the selection for growth and wood characteristics it's possible at this age, as resulted in other type of experiments (YILDIRIM et al., 2011).

Due to the big differences among populations, genetic gain can be improved by switching to advanced generations of selection (KLAPSTE et al., 2007). Indeed, both trial sites exhibited high values of intrapopulation variability. This can be used in future breeding programs, including the selection of some valuable genitors that do not belong to the populations with the highest potential of RI.

Considering the quantum of RI, the fact that the populations did not represent homogenous groups with regard to their geographical location attests their phenotypic divergence, even when they originate from the same region. In this context, testing the seed sources in multisite comparative trials proved to be really useful. In fact, divergent results in various site conditions of the same type of biological material have been observed for Norway spruce in several studies (ENESCU, 1996; RAISKILA et al., 2006; MIHAI, 2009). The average differences between the annual RI values in each of the 33 populations in the two trials were 0.188 mm (4.7%). The RIs were higher in Brețcu than in Avrig by about 67% of the evaluated seed sources. Most of them (64%) originated from the Eastern and Curvature Carpathians. In fact, only 17.6% of the seed sources originating from this area achieved lower average RIs in Avrig, which is outside the natural distribution range for Norway spruce. The largest difference between the two experiments was recorded for 4-Marginea (Eastern Carpathians), which had a 22% higher value in Brețcu than in Avrig. The smallest differences between the two test locations were observed for 8-Prundul Bârgăului (Eastern Carpathians) and 28-Turda (Western Carpathians), both with only a 0.1% higher radial average increment in Brețcu.

The increment rate for Norway spruce can be considered an effective way of predicting wood density (SKRØPPA and DIETRICHSON, 1999). Smaller radial increments generate superior values of wood density (BLOUIN et al., 1994). A negative influence of temperature and precipitation variation on radial increment from the second half of the growing season was reported by BOURIAUD et al. (2005), while a reduction of radial increments increased wood density because of summer wood production. Our correlative analysis for RI, LWP and CWD in the two sites indicates likewise the influence of temperature and precipitation recorded during the growing season. Thus, on the one hand, the precipitation amount is higher in Avrig by about 15%. On the other hand, in Brețcu trial, which has a higher altitude of about 500 m than Avrig, the average temperature is lower by 6.3% in the first two months of the growing season, respectively by 4.5% in last two months. In these circumstances, in the Brețcu trial the mean values are smaller for CWD but higher for LWP. The LWP was higher in Brețcu for all seed sources tested, the overall average difference between population values of the two comparative trials being 59.3%. The highest differences resulted for the Western Carpathian populations, on average 68.9%.

The low values of coefficients of variation for radial increment for many populations from the Eastern Carpathians may be due to the existence of Norway spruce with resonance wood in that part of Romania. Recent research carried out in Eastern Carpathians concerning Norway spruce resonance wood characteristics for the musical instrument industry (ALBU, 2010) showed that its formation began at the age of 30 years, where the rings have a width of up to 2.5 to 3.5 mm. Also, the trees belonging to this biotype are characterized by a highly uniform annual ring width (up to 40% for the rings regularity index) and the proportion of late-

wood not exceeding 30% of the total width of the annual rings. Such trees with potential for resonance wood were identified in the progenies of trees originating from the populations 1-Coșna and 3-Frasin (Eastern Carpathians), in Brețcu trial. Furthermore, the selection of biotypes with the appropriate characteristics for resonance wood can be one of the auxiliary objectives for consideration in further evaluations that will be made in these comparative trials.

Comparative analysis of LWP values revealed obvious differences between the two sites (24.2% in Avrig and 37.9% in Brețcu). The LWP was higher in Brețcu for all seed sources tested, the overall average difference between population values of the two comparative trials being 59.3%. The highest differences resulted for the Western Carpathian populations, on average 68.9%. The higher values registered in Brețcu could be explained from the perspective of its location within the natural distribution range of Norway spruce, which has a higher altitude of about 500 m than Avrig. In these circumstances, there are climatic differences between the two sites that could explain the different values for LWP. For example, in Brețcu trial the average temperature in the first two months of the growing season is lower by 6.3% than Avrig and this can reduce the amount of earlywood. At the same time, seed sources that were tested were located mostly in the mountainous areas, while Avrig is located outside of Norway spruce's natural range, in a pre-mountainous fitoclimatic region.

The smallest differences between the two trials regarding LWP were recorded in 32-Câmpeni (an extra 4.5% in Brețcu), followed by 31-Sudrigiu (an extra 6.1% in Brețcu), while the largest differences were in 27-Beliș (an extra 19.9% in Brețcu), followed by 29-Beiuș (an extra 19.7% in Brețcu). Higher values of latewood percentages for Nordic provenances were also reported by SKRØPPA and DIETRICHSON (1999) in a test with 15 provenances from Norway.

Similar results to those from the Avrig trial were recorded by ZUBIZARRETA GERENDIAIN et al. (2007, 2008) for a stand located in southeast Finland at an altitude of 60 m, where the latewood percentage was between 18 and 26%. MIINA (2000) obtained an average of 24% for the latewood percentage in a natural stand in eastern Finland, while MÄKINEN et al. (2002) reported an average of 20%. In Romania, in a Southern Carpathian population located at about 1000 m in altitude, STĂNESCU and ȘOFLETEA (1992) observed an average latewood proportion of about 19%.

Regarding CWD, due to the very small differences among the populations within the same location, the coefficients of variation were only 2.87% in Avrig and 2.74% in Brețcu. Our results are consistent with those from the literature (GINDL et al., 2000; JYSKE et al., 2008), which also demonstrate a low level of interpopulational variability of wood density. However, the ANOVA test revealed significant differences among populations. Moreover, the values measured for this wood trait were similar to those reported in other studies in Romania (DUMITRIU-TĂTĂRANU et al., 1983; STĂNESCU

and ȘOFLETEA, 1992; PĂRNUȚĂ, 2008). In Norway, HYLEN (1997) recorded values that were smaller by 13.8% of the Avrig trial average value and 8.8%. In Finland, a 20-year old comparative clonal trial indicates an average density of about 0.36 g/cm³ (ZUBIZARRETA GERENDIAIN et al., 2009). This value is higher than the one from our study and that of HYLEN (1997). Higher values of wood density for northern provenances were also observed in a 15-provenance test conducted in Norway by SKRØPPA and DIETRICHSON (1999).

Considering that wood density is under strong genetic control, but ring width and proportion of latewood are with low heritability (ZHANG and JIANG, 1998), selection related to this trait becomes more important. Except one population from the Eastern Carpathians (5-Moldovița), all the other populations displayed lower wood density values in Brețcu, in the natural range of Norway spruce. For this trait, the average difference demonstrated between the two sites was 5.8%, without any notable differences related to the population's origin. A previous study conducted in Romania (STĂNESCU and ȘOFLETEA, 1992) for two field tests located at altitudes of 1040 and 1400 m revealed similar results.

Conclusions

Concerning the Norway spruce populations from the Romanian Carpathians, the data analysis from two locations regarding RI and LWP showed a large interpopulational variability, while for wood density, the variability was lower; intrapopulational variability was also high, these results suggesting that the selection of the most valuable trees from the most valuable populations could be possible and lead to a higher genetic gain.

Regarding RI, the best performances were recorded for the populations from the Eastern Carpathians and Apuseni Mountains, while the Southern Carpathian provenances exhibited a lower increment potential. Summing the data from the two sites, one located outside the natural range of Norway spruce (Avrig) and the other in its ecologically optimum range (Brețcu), the largest RI was recorded in the population 27-Beliș, originating from the Apuseni Mountains, followed by 8-Prundul Bârgăului, 32-Câmpeni, 5-Moldovița and 10-Sânmartin.

The highest LWP values were recorded for the populations that were native to the Eastern Carpathians, 95% of them being assigned to the most valuable homogeneous group. At the opposite end, there were the populations from the Western Carpathians. The differences between these two Carpathian branches are part of a gradient variation model characterized by a slight increase in LWP from west to east. On the other hand, although the differences between the RI means at the two sites were relatively small, there were increases for LWP, for which the values were clearly lower outside the natural area of Norway spruce.

The CWD was higher by 5.8% in a pre-mountainous region outside the natural range of Norway spruce, confirming the results from previous studies about a discrete trend of reverse variation with latitude and cor-

rected latitude in the Carpathians. High values for this quantitative trait of wood in both locations were recorded in 17-Nehoiășu, 24-Retezat and 11-Toplița populations.

Taking into account published data (ENESCU and IONIȚĂ, 2002), we observed that when the trees became older, the amplitude of variation of the different increment and wood traits became larger, leading to changes in the population rankings over time. This will require further periodic evaluations at these sites after age of 30 of trees.

Regarding the examined traits and analyzing the behavior of populations at both sites, we can conclude that the most stable populations were 8-Prundul Bârgăului, 20-Domnești, 19-Azuga, 21-Orăștie, 14-Tarcău, 17-Nehoiășu and 32-Câmpeni. The first and last population above filled the top positions in the rankings for RI. The 16-Nehoiu population also stood out by its high values of wood density.

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