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RESPONSE OF NORWAY SPRUCE (*Picea abies* (L.) H. Karst) SEED STAND PROGENIES TESTED UNDER DIFFERENT SITE CONDITIONS

REAKCIJA POTOMSTVA IZ SJEMENSKIH SASTOJINA OBIČNE SMREKE (*Picea abies* (L.) H. Karst.) TESTIRANIH U NA RAZLIČITIM STANIŠTIMA

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Summary

The aim of this study was to analyse the response of 33 seed stand progenies of Norway spruce, originating from the Romanian Carpathians, in terms of growth and wood characteristics, in trials located inside (Breţcu and Gurghiu) and outside (Avrig and Câmpina) of their natural distribution. Thirty years after planting, measurements were performed for the following traits: total height (TH), average volume per tree (AV/T), radial increment (RI), latewood percentage (LP) and conventional wood density (CWD). Correlation coefficients between the evaluated traits, on one hand, and the geographical coordinates (latitude, longitude and altitude) and ecophysiological latitude of seed stands origin, on the other, were also determined. ANOVA revealed significant ($P < 0.01$) differences among populations for all traits, with the exception of RI, suggesting that it is possible to make a selection at the populations level. Generally, the most valuable populations for TH and RI originate from Eastern and Western Carpathians. High values for LP were recorded mainly for populations originating from Eastern Carpathians. Compared to the two trials installed inside the natural range, the values for RI, TH and AV/T diminished only in one of the two tests installed outside the natural range (Câmpina), but the value for CWD increased. This pattern of expression of traits in the two trials located outside the natural range was explained by the different climatic conditions in two areas: the thermo-pluviometric factor in May-September period (TP_{V-IX}) is 25.3 in Avrig, and only of 21.7 in Campina trial. On the other hand, on overall and in all the Carpathians branches, for latewood proportion there was a significant decrease ($P<0.001$) in the two tests outside the natural range. Significant interaction ($P<0.001$) between population and site trial was found for RI, TH, LP and AV/T. At the same time, the traits analyzed showed low intensity correlations between their values in the four trials and geographical location (altitude, latitude, longitude and ecophysiological latitude) of seed sources origin. The IUFRO standard provenance (Moldoviţa) was one of the most valuable population for the ensemble of all trials. The results of this study allowed the identification of the best populations in each trial that can be used to establish new plantations in similar ecological conditions.

KEY WORDS: comparative trials, Norway spruce, quantitative traits, radial increment, wood density.

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INTRODUCTION
UVOD

Norway spruce (*Picea abies* (L.) H. Karst.) is one of the most important tree species in European forests, both in ecological and socio-economic terms. It is estimated that in the last 200 years, intensive spruce plantations were carried out both within and outside the species' natural range, occasionally affecting the populations adaptability to local environmental conditions (Latalowa and Van der Knaap 2005).

In Romania, the natural altitudinal limit of Norway spruce is between 800 and 1600 m a.s.l. (Feurdean et al. 2011), but pure stands rarely descends below 1000 m a.s.l. Of the total area occupied by Norway spruce, which represents 23.3% of all Romanian forests (INS 2011), around 22% – mostly located in the Subcarpathian hills – consists of plantations established outside of the species' natural range. In the last decades, the health status and stability of these stands at low altitude has been deteriorated.

The superior genetic value of the Romanian spruce populations has been demonstrated in a number of tests carried out across Europe, focusing mainly on the species' bioaccumulation potential, wood quality and adaptability. The two most valuable provenances, Marginea and Moldoviţa, originate from Eastern Carpathians (Schmidt-Vogt 1977; Héois & Van de Sype 1991; Matras 1997; Skrøppa 2005; Ujvari & Ujvari 2006; Mihai 2009). Additionally, provenance Moldoviţa was nominated by International Union of Forest Research Organizations (IUFRO) as provenance of reference, in 1996.

The field trials analysed in the present paper focus on testing the genetic value of 33 seed stands selected on the basis of phenotypic criteria. Five quantitative traits were examined 30 years after planting: tree height (TH), average volume per tree (AV/T), radial increment (RI), latewood percentage (LP) and conventional wood density (CWD). The research objectives were:

(i) to assess the performances of the 33 populations under specific environmental conditions of the four trials, focusing on two groups: progeny tested in their natural range (*INR*) and outside their natural range (*ONR*), respectively;

Table 1 Location and climatic conditions in comparative trials
Tablica 1. Položaj pokusnih ploha i klimatski uvjeti

Trial / testing variant *Pokusna ploha*	Location/altitude (m) *Položaj/nadmorska visina (m)*	Exposition Slope Soil *Ekspozicija Nagib Tlo*	Climatic conditions *Klimatski uvjeti*			
			Average annual temperature* (°C) *Prosječna godišnja temperature (°C)*	Average annual precipitation* (mm) *Prosječna godišnja oborina (mm)*	TPF V-IX**	AI V-VII***
Avrig *ONR*	615 m 45°39'36"N 24°26'12"E	flat surface 0° Eutric cambisol *Ravno 0° Eutrični kambisol*	8.3	680	25.3	41.3
Câmpina *ONR*	570 m 45°11'11"N 25°48'47"E	southeast 15° Eutric cambisol *Jugoistočna 15° Eutrični kambisol*	9.3	645	21.7	35.9
Breţcu *INR*	1100 m 45°58'16"N 26°24'12"E	northeast 15° Eutric cambisol *sjeveroistočna 15° Eutrični kambisol*	4.8	830	40.8	61.7
Gurghiu *INR*	1000 m 46°48'13"N 25°03'58"E	north 25° Eutric cambisol *sjeverna 25° Eutrični kambisol*	5.7	810	32.8	49.1

*Average values for the 1985–2010 interval (ANM 2011) – Prosječne vrijednosti za razdoblje 1985–2010 (ANM 2011)
**Thermo-pluviometric factor May-September (Schmidt-Vogt 1977) – Termo-pluviometričke vrijednosti svibanj-rujan (Schmidt-Vogt 1977)
***De Martonne aridity index May-July – De Martoneov indeks aridnosti svibanj-srapnj

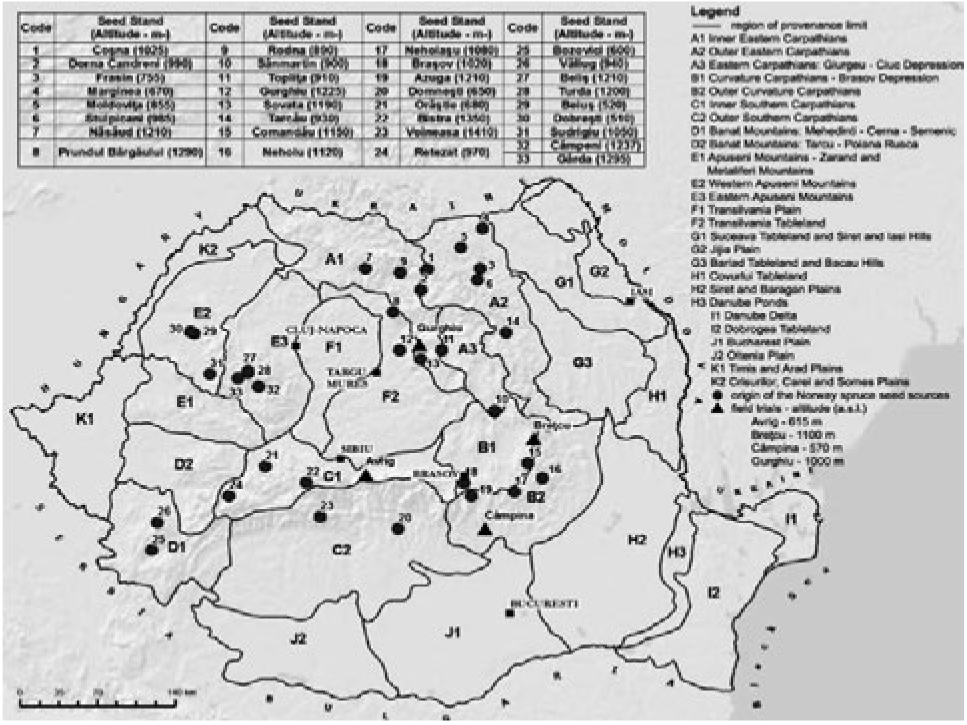

Figure 1 Location of seed stands and field trials on the map of regions of provenance established for Romania. Population code 1–14 are from Eastern Carpathians (region A), 15–19 = Curvature Carpathians (region B), 20–24 = Southern Carpathians (region C) and 25–33 are from Western Romanian Carpathians (regions D and E).

Slika 1. Lokacija sjemenskih sastojina i pokusnih ploha na karti provenijencija u Rumunjskoj

(ii) to analyse the behaviour of local provenances and also for one of the most valuable provenance after IUFRO standard (5-Moldoviţa);

(iii) to evaluate how populations originating from different branches of the Romanian Carpathians respond at the four local environmental conditions;

(iv) to evaluate any correlations between analysed traits and the geographical position (latitude, longitude, altitude and ecophysiological latitude) of the seed stands origin.

Also, the experimental data will be useful for the conservation of genetic resources in this important Norway spruce area.

MATERIALS AND METHODS
MATERIJALI I METODE

Four field trials (Table 1) were established using seedlings obtained from bulked seed harvested from 10 seed trees belonging to each of the 33 seed stands presented in Figure 1, referred to as *populations* (indicating the origin of seed sources). Two trials (Breţcu and Gurghiu) were installed inside the natural range and other two (Avrig and Câmpina) outside it. Both trials established in the natural range belong to the ecological optimum for Norway spruce in Romanian Carpathians (Feurdean et al. 2011). After Stănescu et al. (1997), the average annual temperature and the amount of precipitation in the two tests outside of the natural range (Table 1) are suboptimal, mainly in Câmpina trial.

In all trials, the experimental design was an incomplete balanced square grid, with three repetitions and 49 seedlings per plot planted at a spacing interval of 2 by 2 m; every population was composed of progenies obtained from bulked seed harvested from 10 trees from every seed stand (Enescu & Ioniţă 2002). The experimental design was of the 6 × 6 type (Şofletea et al. 2012). To realize the 6 x 6 experimental design, in each replication three populations (the ones with the code numbers 1, 2 and 3) were repeated.

Following the methodology developed by IUFRO (Lines 1967) regarding data collection in such field trials, evaluations of 10 trees were made in each unitary plot, being assessed 30 trees per population and 1080 trees per trial, respectively.

Thirty years after planting, tree height was measured using a Vertex III instrument, with tree volume determined via the volume regression equation method (Giurgiu et al. 2004). In each trial, nine trees from each population (three in each repetition, belonging to the mean diameter category) were selected in order to extract increment cores using a Pressler borer. The following traits were evaluated: RI (annual radial increments), width of earlywood and latewood and their average values in population and in trial, LP (proportion of latewood in the total width of annual ring) and CWD (conventional wood density; method presented in Şofletea et al. 2012).

Measurement of RI and earlywood/latewood values was carried out using a Rinntech LINTAB 5 tree-ring measurement station (RINNTECH, Heidelberg, Germany, www.

rinntech.com), with recordings and initial data processing undertaken using the TSAP Win software program (www.rinntech.de). The constructive features of the device allow a standard resolution of 1:100, while a Leica stereomicroscope (Leica Microsystems, Wetzlar, Germany, www.leica-microsystems.com) provided an enlargement factor of 6:1 (Badea 2008).

All statistical analysis was performed in the Statistica 8.0 software program, with graphs drawn using a combination of Excel and Statistica 8.0. Kolmogorov-Smirnov test was applied to check the normality of distribution and the assumptions of ANOVA were verified using Levene's test. ANOVA was used to determine the variance components reflecting the influence of populations and repetitions, as well as that of residual variance. Considering the employed experimental design, the mathematical model selected for variance analysis was that 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 repetitions (j = 1...b), ε_{ij} = random error affecting ij plots.

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

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

Where: m and α_i are as above, β_j = component of j locations (j = 1...b), $\alpha\beta_{ij}$ = interaction of i populations with j locations, ε_{ijk} = error caused by random events.

The level of significance was determined using *Fisher's* (F) test, with population ranking and homogeneous groups determined using *Duncan's* test for a transgression probability of 5%. In addition, Pearson correlations between traits and the geographical coordinates of the seed stand origins were also determined. For the latter, the ecophysiological latitude (Le = L + A / 100) was taken to represent the latitude (L) corrected by altitude (A) in such way that a 100 m difference in altitude is considered equal to one degree of latitude (Wiersma 1962).

RESULTS
REZULTATI

Total height (TH) – Ukupna visina (UV)

Identical average TH value was observed in both trials established *INR* (17.0 m) which was similar to that seen in the Câmpina trial, situated *ONR* (16.9 m). In the second trial located *ONR* (Avrig) TH average value was significantly higher (11%) – Table 2.

ANOVA (Table 3) revealed significant differences within populations (P < 0.001) in all trials. Bifactorial analysis of variance (Table 4) demonstrated the existence of not only a strong site influence (P < 0.001), but also a highly significant population × site interaction, suggesting different reaction of populations to the change of environmental conditions. This conclusion is valuable also for AV/T, RI and LP (Table 4).

In the two trials established *ONR*, the most valuable seed stands were found to be those originating from Eastern and

Table 2 Mean results for each trial 30 years after planting
Tablica 2. Srednje vrijednosti mjerenih svojstava 30 godina od osnivanja pokusa

Trial *Pokus*	Analysed traits: Mean value / variation coefficient (%) / amplitude of variation *Analizirana svojstva: srednja vrijednost/koeficijent varijacije (%)/ raspon*				
	Total height (m) *Ukupna visina (m)*	Average volume / tree (m^3) *Prosječan volumen stabla (m^3)*	Radial increment (mm) *Radijalni prirast (mm)*	Latewood percentage (%) *Postotak kasnog drva (%)*	Conventional Wood density (g/cm^3) *Standardna gustoća drva (g/cm^3)*
Avrig	18.8 3.7 17.4–20.1	0.293 14.3 0.211–0.373	4.053 5.2 3.66–4.533	24.2 14.1 16.8–31.1	0.348 2.9 0.327–0.366
Câmpina	16.9 2.4 16.0–17.7	0.179 6.7 0.154–0.208	3.713 5.8 3.051–4.104	20.3 7.4 17.8–24.9	0.374 3.2 0.356–0.398
Breţcu	17.0 2.4 16.0–17.9	0.291 8.6 0.237–0.346	4.104 4.6 3.799–4.647	37.9 7.7 30.6–43.1	0.329 2.7 0.314–0.350
Gurghiu	17.0 2.2 16.1–17.6	0.209 7.4 0.186–0.264	3.980 5.4 3.547–4.445	25.9 7.3 21.8–32.8	0.348 2.0 0.336–0.364

Table 3 ANOVA for total height (TH), average volume per tree (AV/T), radial increments (RI), latewood percentage (LP) and conventional wood density (CWD) of Norway spruce populations, by location

Tablica 3. ANOVA za ukupnu visinu (UV), prosječni volumen po stablu (PV/S), radijalni prirast (RP), postotak kasnog drva (PKD) i standardnu gustoću drva (SGD) zajednica obične smreke, prema lokaciji

Source of variance *Izvor varijabiliteta*	Phenotypical Traits *Fenotipska svojstva*		Wood traits *Drvna svojstva*		
	Avrig trial (traits / mean squares)				
	TH *(UV)*	AV/T *(PV/S)*	RI *(RP)*	LP *(PKD)*	CWD *(SGD)*
Replication *Ponavljanje*	1.9	0.018	14.2***	898.6***	0.002**
Population *Populacija*	14.8***	0.053***	0.392**	107.8**	0.001*
Error *Pogreška*	3.9	0.024	0.196	57.1	0.000
	Câmpina trial (traits / mean squares)				
	TH	AV/T	RI	LP	CWD
Replication *Ponavljanje*	127.3***	0.062***	3.48***	119.1**	0.002*
Population *Populacija*	4.9***	0.005	0.426***	23.6	0.001***
Error *Pogreška*	1.9	0.004	0.200	17.2	0.001
	Breţcu trial (traits / mean squares)				
	TH	AV/T	RI	LP	CWD
Replication *Ponavljanje*	0.4	0.038	2.64***	2363.6***	0.0000
Population *Populacija*	4.8**	0.020	0.336	78.8***	0.0007*
Error *Pogreška*	2.6	0.018	0.236	27.4	0.0004
	Gurghiu trial (traits / mean squares)				
	TH	AV/T	RI	LP	CWD
Replication *Ponavljanje*	17.8**	0.001	2.05**	215.1***	0.0006
Population *Populacija*	4.4*	0.007	0.55	44.8**	0.0005
Error *Pogreška*	2.8	0.005	0.388	26.1	0.0007

Degrees of freedom for the phenotypical traits: Replication = 2, population = 35, error = 1042; for the wood traits: error = 286; *P < 0.05, **P < 0.01, ***P < 0.001; 1080 trees / trial, 324 cores / trial.

Stupanj slobode za fenotipske pokusne plohe: Replikacija = 2, nastanjenost = 35, greška = 1042; Za obilježja drva: greška = 286; *P < 0.05, **P < 0.01, ***P < 0.001; 1080 stabala po pokusnoj plohi, 324 izvrtka po pokusnoj plohi.

Western Carpathians (18.0 m average), while the lowest values were registered in populations from Southern Carpathians (17.6 m average). In Avrig trial, the population sourced from an area located closest to the test site (22-Bistra) ranked 14th, while in Câmpina trial the nearest population (19-Azuga) ranked first, suggesting a superior adaptability of this local population to the restrictive environmental conditions existing in the second location (see Table 1).

In the two trials established *INR*, the performance of nearest seed source varied: the local population (12-Gurghiu) ranked 10th in Gurghiu trial, while the nearest seed source towards Breţcu (15-Comandău) ranked 25th.

Table 4 ANOVA for total height (TH), average volume per tree (AV/T), radial increments (RI), latewood percentage (LP) and conventional wood density (CWD) of Norway spruce populations combined over locations

Tablica 4. ANOVA za ukupnu visinu (UV), prosječni volumen po stablu (PV/S), radijalni prirast (RP), postotak kasnog drva (PKD) i standardnu gustoću drva (SGD) zajednice obične smreke, kombinirano prema lokacijama

Source of variance *Izvor varijabiliteta*	Phenotypical Traits/ Mean square *Fenotipska svojstva/*		Wood traits/Mean square *Drvna svojstva/*		
	TH	AV/T	RI	LP	CWD
Location *Lokacija*	974***	3.649***	9.95***	18878***	0.111***
Population *Populacija*	10***	0.025***	0.29	84.6***	0.002***
Population × location *Populacija × lokacija*	6***	0.02***	0.47***	56.9**	0.0005
Error *Greška*	3	0.013	0.29	38.0	0.0005

Degrees of freedom for the phenotypical traits: location = 3, population = 35, population × location = 105, error = 4176; for the wood traits: error = 1152; * P < 0.05, ** P < 0.01, *** P < 0.001; 4320 trees per all four trials, 1296 cores used.

*Stupnjevi slobode za fenotipske pokusne plohe: lokacija = 3, nastanjenost = 35, nastanjenost x lokacija = 105, greška = 4176; Za obilježja drva: greška = 1152; * P < 0.05, ** P < 0.01, *** P < 0.001; 4320 stabala za sve četiri pokusne plohe, 1296 korištena izvrtka.*

Average volume per tree (AV/T) – Prosječni volumen po stablu (PV/S)

The average AV/T of the two *ONR* trials (0.236 m^3) is 5% lower than *INR* trials (0.250 m^3), due to the lowest value registered in Câmpina trial (0.179 m^3). On the contrary, in the second *ONR* trial (Avrig) has been recorded the most active growth out of all testing site (0.293 m^3). At the same time, the very large difference (64%) between the two *ONR* trials should be noted.

Significant differences among populations (P>0.001) were found only in Avrig trial (Table 3).

Among the top 10 ranking populations in the two *ONR* trials, five originated from Eastern Carpathians and four from Western Carpathians. In Avrig trial, the population from the area closest to the testing site (22-Bistra) ranked in the middle; in Câmpina trial, the nearest source population (19-Azuga) ranked 2nd, confirming the population's adaptability to this site already observed and mentioned for TH.

Cumulating the data registered in the *INR* trials, the highest values for AV/T resulted for a seed source originate from Eastern Carpathians (12-Gurghiu; 0.283 m^3) and also for two from Western Romanian Carpathians (32-Câmpeni= 0.282 m^3 and 28-Turda= 0.272 m^3); the local population in Gurghiu trial and respectively the nearest from testing site in Brețcu trial were ranked in the first third.

In the cumulative ranking of all the four trials, five populations of the top 10 were from the Eastern and four from the Western Carpathians.

Radial increments (RI) – Radijalni prirasti (RP)

The highest RI average value was registered in Brețcu trial, *INR* (4.104 mm/year), and the lowest in the Câmpina trial, *ONR* (3.713 mm/year). The average of the two *ONR* experiments (3.883 mm/year) was 4.1% lower than those of *INR* trials (4.042 mm/year), even if the average result in Avrig was almost identical to that from the *INR* trials. ANOVA and Duncan tests (Table 3 and Figure 2) have revealed non-significant influences of population in both *ONR* trials, but significant for *INR*.

Cumulating the values of the two *INR* tests, the first position in the ranking was occupied by population 4-Marginea (4.405 mm/year), followed by 28-Turda and 12-Gurghiu. Among the most valuable 10 populations, five originated from Eastern Carpathians and three from Western Carpathians. The local population ranked 2nd in Gurghiu trial, after population 28-Turda (Figure 2).

Relating to performance of population 5-Moldovița, which was considered as standard by IUFRO, it was ranked 1st in Avrig and 12th in Gurghiu trial, but only in the second part of the ranking in the two other trials.

In terms of RI values registered in all four trials, among the top ten populations, eight originate from Eastern and Western Carpathians (four from each branch). For the cumulative values in all four trials, the average RI is higher for populations originate from Eastern Carpathians, while the populations originate from Southern Carpathians achieved small but more stable values.

Latewood percentage (LP) – Postotak kasnog drva (PKD)

The lowest LP values were recorded in Câmpina (20.3%) and the highest (37.9%) in Brețcu trials (Table 2), which corresponds to the lowest and the highest altitude, respectively. For all four experiments, a direct but not significant simple Pearson correlation between LP and site altitude (r = 0.84) resulted. On average, *ONR,* the latewood represents 22.3% of RI, whereas *INR* the average was 31.9%. Analysis of variance (Table 3) revealed a higher level of variation in populations grown in their natural habitat or in satisfactory environmental conditions in Avrig trial, *ONR*. Low level of variation resulted in the difficult environmental conditions of the Câmpina trial, probably as a result of the selective pressure of the environment.

ONR, among the top ten-ranked populations in terms of LP value, five originate from Eastern Carpathians and three from Curvature Carpathians (ecological region B in figure 1, located at the southern end of the Eastern Carpathians), and the closest to the both trial sites were ranked in the second quarter (Figure 3). *INR*, in the ranking of first ten populations was registered an increased proportion of those originating from the Eastern Carpathians (about 70%).

For the IUFRO standard provenance (5-Moldovița), higher values of LP than the average of all populations were registered both *INR* (17.3% more than the mean of all popula-

Population	Avrig -mm-	5%				
5	4.533	***				
32	4.407	***	***			
10	4.395	***	***			
8	4.343	***	***	***		
27	4.331	***	***	***		
24	4.230	***	***	***	***	
30	4.216	***	***	***	***	
25	4.203	***	***	***	***	
28	4.201	***	***	***	***	
22	4.172	***	***	***	***	
23	4.168	***	***	***	***	
26	4.156	***	***	***	***	***
1	4.144	***	***	***	***	***
15	4.111	***	***	***	***	***
19	4.044		***	***	***	***
11	4.043		***	***	***	***
3	4.038		***	***	***	***
29	4.018		***	***	***	***
2	4.006		***	***	***	***
13	3.999		***	***	***	***
18	3.982		***	***	***	***
9	3.965		***	***	***	***
21	3.948		***	***	***	***
6	3.946		***	***	***	***
20	3.927		***	***	***	***
7	3.879			***	***	***
4	3.822				***	***
12	3.814				***	***
31	3.795				***	***
33	3.768				***	***
14	3.764				***	***
17	3.733				***	***
16	3.660					***

Population	Câmpina -mm-	5%			
16	4.104	***			
15	3.963	***	***		
30	3.956	***	***		
18	3.949	***	***		
8	3.929	***	***		
17	3.903	***	***		
7	3.902	***	***		
24	3.886	***	***		
6	3.863	***	***		
2	3.843	***	***		
14	3.820	***	***		
29	3.817	***	***		
13	3.812	***	***		
9	3.793	***	***		
20	3.763	***	***		
3	3.762	***	***		
19	3.747	***	***	***	
32	3.727	***	***	***	
5	3.719	***	***	***	
25	3.689	***	***	***	
23	3.688	***	***	***	
12	3.677	***	***	***	
4	3.623	***	***	***	
31	3.602	***	***	***	
22	3.590		***	***	
10	3.571		***	***	
33	3.536		***	***	
1	3.515		***	***	
21	3.507		***	***	
26	3.505		***	***	
11	3.460		***	***	***
28	3.259			***	***
27	3.051				***

Population	Brețcu -mm-	5%	
4	4.647	***	
27	4.362	***	***
8	4.346	***	***
9	4.313	***	***
1	4.307	***	***
18	4.297	***	***
32	4.245	***	***
28	4.206	***	***
26	4.195	***	***
11	4.184	***	***
2	4.181	***	***
3	4.177	***	***
15	4.167	***	***
30	4.162	***	***
12	4.147	***	***
10	4.140	***	***
19	4.137	***	***
6	4.127	***	***
21	4.113	***	***
22	4.086		***
31	4.021		***
5	4.014		***
33	3.972		***
23	3.952		***
17	3.937		***
29	3.936		***
24	3.910		***
16	3.903		***
7	3.897		***
20	3.882		***
25	3.872		***
13	3.805		***
14	3.799		***

Population	Gurghiu -mm-	5%			
28	4.445	***			
12	4.341	***	***		
25	4.318	***	***	***	
30	4.215	***	***	***	***
11	4.199	***	***	***	***
4	4.162	***	***	***	***
22	4.158	***	***	***	***
9	4.155	***	***	***	***
6	4.126	***	***	***	***
18	4.102	***	***	***	***
21	4.055	***	***	***	***
5	4.050	***	***	***	***
33	4.046	***	***	***	***
17	4.044	***	***	***	***
27	4.025	***	***	***	***
20	4.020	***	***	***	***
3	3.982	***	***	***	***
19	3.961	***	***	***	***
26	3.960	***	***	***	***
15	3.936	***	***	***	***
32	3.931	***	***	***	***
23	3.890	***	***	***	***
10	3.872	***	***	***	***
29	3.869	***	***	***	***
13	3.862	***	***	***	***
7	3.823	***	***	***	***
2	3.791	***	***	***	***
24	3.735	***	***	***	***
14	3.730	***	***	***	***
31	3.714		***	***	***
16	3.682		***	***	***
8	3.596			***	***
1	3.547				***

Figure 2 Duncan test for radial increment (homogeneous groups for 5% transgression probability)
Slika 2. Duncan-ov test radijalnog prirasta (homogene grupe uz 5% vjerojatnosti pogreške)

Population	Avrig -%-	5%					
5	31.1	***					
6	30.3	***	***				
17	28.5	***	***	***			
15	28.1	***	***	***			
8	27.6	***	***	***	***		
19	27.4	***	***	***	***		
20	27.1	***	***	***	***		
14	26.7	***	***	***	***		
16	26.5	***	***	***	***	***	
2	26.3	***	***	***	***	***	
4	26.1	***	***	***	***	***	
32	26.1	***	***	***	***	***	
31	25.7	***	***	***	***	***	
11	25.5	***	***	***	***	***	
23	25.0	***	***	***	***	***	***
9	24.9	***	***	***	***	***	***
7	24.7	***	***	***	***	***	***
1	24.4	***	***	***	***	***	***
21	23.7	***	***	***	***	***	***
22	23.1	***	***	***	***	***	***
33	22.9	***	***	***	***	***	***
26	22.8	***	***	***	***	***	***
24	22.7	***	***	***	***	***	***
25	22.4		***	***	***	***	***
10	21.9		***	***	***	***	***
27	21.3			***	***	***	***
12	21.3			***	***	***	***
3	20.8			***	***	***	***
29	20.1			***	***	***	***
18	20.0			***	***	***	***
13	19.2				***	***	***
28	17.9					***	***
30	16.8						***

Population	Câmpina -%-	5%			
2	24.9	***			
27	23.2	***	***		
29	22.8	***	***	***	
32	22.7	***	***	***	
10	21.7	***	***	***	***
15	21.6	***	***	***	***
8	21.4	***	***	***	***
14	21.3	***	***	***	***
5	21.0	***	***	***	***
9	20.8	***	***	***	***
33	20.6	***	***	***	***
13	20.3		***	***	***
12	20.2		***	***	***
25	20.1		***	***	***
28	20.1		***	***	***
11	20.0		***	***	***
3	20.0		***	***	***
19	19.9		***	***	***
1	19.9		***	***	***
31	19.9		***	***	***
17	19.8		***	***	***
24	19.8		***	***	***
6	19.6		***	***	***
26	19.6		***	***	***
20	19.5		***	***	***
23	19.1		***	***	***
4	19.0		***	***	***
7	18.8		***	***	***
22	18.7		***	***	***
16	18.5		***	***	***
21	18.4		***	***	***
30	18.1			***	***
18	17.8				***

Population	Breţcu -%-	5%							
6	43.1	***							
7	42.2	***	***						
5	42.1	***	***	***					
9	41.3	***	***	***	***				
27	41.2	***	***	***	***				
8	40.8	***	***	***	***	***			
4	40.8	***	***	***	***	***			
2	40.2	***	***	***	***	***	***		
29	39.8	***	***	***	***	***	***		
12	39.4	***	***	***	***	***	***		
17	39.0	***	***	***	***	***	***		
14	38.8	***	***	***	***	***	***		
3	38.7	***	***	***	***	***	***		
13	38.5	***	***	***	***	***	***		
26	38.3	***	***	***	***	***	***		
11	38.1	***	***	***	***	***	***		
1	37.8	***	***	***	***	***	***	***	
15	37.7	***	***	***	***	***	***	***	
23	37.7	***	***	***	***	***	***	***	
24	37.4	***	***	***	***	***	***	***	
18	37.2	***	***	***	***	***	***	***	
16	37.0	***	***	***	***	***	***	***	
10	36.9		***	***	***	***	***	***	
28	36.7		***	***	***	***	***	***	
19	35.9			***	***	***	***	***	***
20	35.7				***	***	***	***	***
22	35.6				***	***	***	***	***
25	35.4				***	***	***	***	***
33	35.3				***	***	***	***	***
21	34.8					***	***	***	***
30	34.0						***	***	***
31	31.8							***	***
32	30.6								***

Population	Gurghiu -%-	5%		
22	32.8	***		
2	28.4	***	***	
29	28.1	***	***	
1	28.0	***	***	
5	27.0		***	***
13	26.9		***	***
24	26.8		***	***
6	26.8		***	***
3	26.8		***	***
31	26.6		***	***
28	26.5		***	***
25	26.5		***	***
21	26.4		***	***
8	26.1		***	***
7	26.1		***	***
23	26.1		***	***
27	25.9		***	***
32	25.9		***	***
11	25.9		***	***
26	25.8		***	***
16	25.7		***	***
15	25.4		***	***
30	25.4		***	***
4	25.3		***	***
10	25.2		***	***
33	25.2		***	***
12	24.9		***	***
17	24.4		***	***
9	24.1		***	***
14	23.6		***	***
20	22.9		***	***
19	22.7		***	***
18	21.8			***

Figure 3 Duncan test for the proportion of latewood (homogeneous groups for 5% transgression probability). Populations from the Eastern Carpathians are highlighted

Slika 3. Duncan-ov test za udio kasnog drva (homogene grupe uz 5% vjerojatnosti pogreške). Populacije istočnih Karpata su posebno istaknute

tions) and *ONR* (8.3% more than the mean of all populations) – figure 4.

Conventional wood density (CWD) – Standardna gustoća drva (SGD)

The mean value of CWD in the two *ONR* trials was 6.5% higher than *INR*. However, the greater average value in the two tests *ONR* is due to Câmpina trial, which has the highest CWD value (0.374 g/cm^3). The highest CWD value was recorded at the lowest altitude (Câmpina), whereas the lowest (0.329 g/cm^3) at highest altitude, in Breţcu (Table 2). ANOVA (Table 4) revealed significant differences (P<0.001) of location and population. However, the population has significant effects in the two tests outside the natural range (P<0.001 at Câmpina; P<0.05 at Avrig), but also in one of

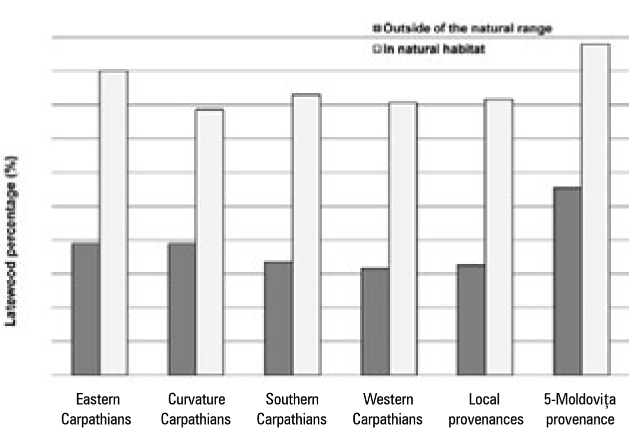

Figure 4 Norway spruce latewood percentage in Romanian Carpathians branches

Slika 4. Postotak kasnog drva obične smreke u rumunjskim Karpatima

the tests in the natural area of species (P<0.05 at Breţcu). In all trials, the populations associated with high RI values displayed lower wood density levels. This was also evident in the case of the IUFRO standard provenance (5-Moldoviţa), which was ranked 28th in terms of CWD value.

CORRELATIONS
KORELACIJE

The correlations between analysed traits and the geographical gradients of seed stand origins (Table 5) were insignificant with altitude, while latitude, longitude and ecophysiological latitude determined some influences, but did not result clear trends or patterns to differentiate the behaviour *INR* or *ONR*. Thus, ecophysiological latitude was found to have a small influence on CWD value only in the *INR* trial carried out at Breţcu (r = -0.14*); northern Romanian populations displayed high increments in all tests, but the wood was found to be less dense. At the same time, the Breţcu trial (*INR*), where the highest mean annual RI value was recorded, was the only in which a significant but low correlation was observed between mean RI and latitude of population origin (r = 0.14*).

DISCUSSION
RASPRAVA

The differences between populations originating from different branches of Romanian Carpathians may be attributed to historical evolution of spruce in Holocene (Feurdean et al. 2011). The lower values obtained in Câmpina trial can

Table 5. Correlation coefficients between analyzed traits and the geographical gradients of seed stands origin
Tablica 5. Koeficijenti korelacije između ispitanih pokusnih ploha i zemljopisnih obilježja sastojina iz kojih dolazi sjeme

Variables *Geografska varijabla*	Total height *Ukupna visina*	Average volume per tree *Prosječan volumen stabla*	Radial increment *Radijalni prirast*	Latewood percent *Postotak kasnog drva*	Wood density *Gustoća drva*	Total height *Ukupna visina*	Average volume per tree *Prosječan volumen stabla*	Radial increment *Radijalni prirast*	Latewood percent *Postotak kasnog drva*	Wood density *Gustoća drva*
	Avrig trial *Pokus Avrig*					Breţcu trial *Pokus Breţcu*				
Latitude (N) *Geogr. širina (N)*	**0.11****	0.05	0.00	0.02	**–0.12***	0.05	0.02	**0.14***	**0.2*****	**–0.12***
Ecoph. latitude	0.00	0.01	0.01	0.08	–0.07	0.04	0.04	0.05	0.08	**–0.14***
Longitude (E)	0.00	–0.02	–0.10	**0.19****	0.06	0.00	–0.01	0.04	**0.17****	0.03
Altitude (m)	–0.04	–0.01	0.01	0.07	–0.02	0.02	0.03	–0.01	0.00	–0.09
	Câmpina trial *Pokus Câmpina*					Gurghiu trial *Pokus Gurghiu*				
Latitude (N)	–0.03	–0.05	0.00	0.07	**–0.13***	–0.03	0.01	–0.05	0.08	0.06
Ecoph. Latitude *Ekofiziološka geografska širina*	–0.04	**–0.06***	–0.03	0.05	–0.05	0.02	0.03	–0.08	0.06	–0.05
Longitude (E) *Geogr. duljina (E)*	0.01	0.04	**0.15***	–0.01	–0.04	–0.02	–0.03	–0.07	–0.08	0.02
Altitude (m) *Nadmorska visina (m)*	–0.03	–0.03	–0.03	0.03	0.00	0.03	0.03	–0.06	0.03	–0.08

Pearson correlation for 1080 trees per trial (TH, AV/T) and for 324 cores / trial (RI, LP, CWD). Ecoph. latitude = Ecophysiological latitude.
Pearsonove korelacije za 1080 stabala po pokusnoj plohi (UV, PV/S) i za 324 izvrtka po pokusnoj plohi (RP, PKD, SGD). Ekofiziološka geografska širina = Ekofiziološka geografska duljina.

be associated with more difficult climatic conditions (thermo-pluviometric factor – TPF and De Martonne indices). The observed value of $TPF_{V\text{-}IX}$ = 21.7, is comparable to the minimum threshold values of 19 and 24 mentioned by Schmidt-Vogt (1977) for Norway spruce in warm/wet and cold/wet climate, respectively.

The average height of the 4320 trees analysed in the four experiments, 30 years after planting, was 17.4 m, a value almost identical to that obtained in Germany (17.2 m) for trees of the same age (Mäkinen & Hein 2006), but 10% to 13% greater than that obtained in France (Loubère et al. 2004). The average height at the same age was around 30% lower in Poland (Matras 2009) and Finland (Mäkinen et al. 2003; Kilpeläinen et al. 2010), and 27% lower in Norway (Steffenrem et al. 2007).

In the two *ONR* trials (Avrig and Câmpina) RI value differed by 9%, most likely due to the limiting site conditions observed at the latter location. The average RI value observed in the present study was 16.5% greater than that recorded in Finland for 20-year old trees (Zubizarreta Gerendiain et al. 2009), and in Norway, in a full-sib test of 30-years old, (Steffenrem et al. 2007), the mean of radial growth was 23.8% lower than *ONR* in the present study. The existence of large variability, both within and among populations, favours transition to the next generations of selection (Klapste et al. 2007) with the inclusion in the selected process of the most valuable trees from the best populations.

However, the above discussed similarities or differences compared to those in other geographical areas cannot be attributed to genetic values of Norway spruce, because we don't have evidences about environmental similarities or differences. Also, the testing performed in our study did not include populations from outside of Carpathians.

In terms of AV/T values, the IUFRO standard provenance, 5-Moldoviţa, performed much better *ONR* (ranking 5th) than in the *INR* trials (25th). Since it is located at the lower altitudinal limit of the natural range of Norway spruce (855 m), this suggests a high adaptability of this particular provenance in areas with longer growing season, at low altitude, in the high hills of Subcarpathian area (the $TPF_{V\text{-}IX}$ value must be greater than 25).

An important finding of this research, in the four trials, is related to decrease of LP outside the natural range, on overall and in all the Carpathians branches (Figure 4). On the other hand, the geographical coordinates of the seed sources origin have small influences (Table 5), but the population effect was significant (P<0.001; Table 3 and Table 4). In the present study, LP values increased with altitude from 20.3% at 570 m to 37.9% at 1100 m. As a result, the LP prediction is possible based on altitudinal location of the planting site, without neglecting the effect of population. Very close values to the average of the four experiments (27.1%) and also of those resulted in the ONR trials (22.3%) were recorded already in an earlier study in Romania (Stănescu & Şofletea 1992). LP values between 18% and 29% were reported in Finland and Norway (Skrøppa et al. 1999; Miina 2000; Mäkinen et al. 2002; Steffenrem et al. 2007; Zubizarreta Gerendiain et al. 2007, 2008).

The average CWD value in the all four trials (0.350 g / cm^3) is also similar to that previously obtained in Romania (Stănescu & Şofletea 1992) and also confirm the values recorded in trials carried out in other geographical regions regarding decreasing of wood density with increasing RI values (Blouin et al. 1994; Bouriaud et al. 2005; Jyske et al. 2008; Zubizarreta Gerendiain et al. 2009), which has implications for both the mechanical and physical properties of the wood. However, the literature data show and differences from our study. Thus, the studies performed in Northern Europe have produced a considerable variety of results, with 8% lower values recorded than those presented here (Hylen 1997; Skrøppa et al. 1999), as well as 17% greater in a full-sib test involving 30-year old trees (Steffenrem et al. 2007). In summer, the monthly aridity values were seen to have an inverse and highly intense influence (r = -0.91 – -0.94) concerning wood density. The same result was recorded in Germany (Van der Maaten-Theunissen et al. 2013).

The ranking of mean values in the four trials concerning the bioaccumulation (TH, AV/T and RI) reveals an asymmetry of response of the two tests installed outside the natural range. Differences between Avrig and Câmpina are the result of more restrictive climatic conditions in the last location. On the other hand, the populations that have high values for LP, have had, in general, high values of the radial growth in the second part of the growing season.

A basic idea of our research was to identify populations able to be adapted in various environmental conditions, to combine the two concepts relating to the transfer of seeds: maximizing growth and minimizing risks (Hamman et al. 2011). To this end, the first step was to identify the populations that have had very good results in each of the four test sites, to be recommended for installing of stands in environmental conditions similar to Avrig (1), Câmpina (2), Breţcu (3) and Gurghiu (4). As a result, according to this criterion the following populations were selected:

(1): 5-Moldoviţa, 32-Câmpeni, 15-Comandău and 28-Turda;

(2): 19-Azuga and 15-Comandău;

(3): 4-Marginea, 32-Câmpeni, 28-Turda and 15-Comandău;

(4): 28-Turda, 12-Gurghiu, 4-Marginea and 5-Moldoviţa.

At the same time, based on the previous selection, some populations have shown a relatively wide capacity to adapt to different environmental conditions, being among those identified as valuable in two or even three of the four test sites. The environmental conditions in the Câmpina test have restricted the populations recommended for installation of stands under similar conditions to only two.

CONCLUSIONS
ZAKLJUČCI

No significant differences between the mean values of all the 33 tested populations resulted between the two INR trials. In contrast, the response of populations in the two ONR tests was asymmetric, especially for TH, RI and AV/T, due to different environmental conditions of the test sites. In our opinion, the TPF_{V-IX} value registered in Avrig trial (25.3) does not interfere negatively in the growth, while the one registered in Campina trial (21.7) should be considered as a minimum for that area or in equivalent situations in the Romanian Carpathians.

The significant differences between seed stands for all studied traits suggest that, in breeding programs, artificial selection at the seed stand level could be possible. The significant seed stand × environment interaction demonstrates that the same seed stand reacts differently to different environmental conditions and the best adaptive populations may be used only in similar ecological conditions to those of the test site.

In all experiments, the populations originating from Eastern and Western Carpathians presented sustained growth, both in height and radial increment. Local provenances were mostly ranked in the first half and the IUFRO standard provenance (5-Moldoviţa) obtained better results in trials located *ONR*. For the ensemble of all experiments, giving equal importance to all of the analyzed growing traits, the highest scores were obtained by the populations: 5-Moldoviţa, 4-Marginea, 15-Comandău, 28-Turda, 32-Câmpeni and 12-Gurghiu. Using seeds from these populations, only in similar environmental conditions, will favor to obtain an important genetic gain, and therefore an economically benefit. Regarding the biomass with high proportion of latewood, the populations originating in the Eastern Carpathians were found to be most suitable, both for INR and ONR stands. A good example of this is that of the 5-Moldoviţa population. On the other hand, the traits analyzed showed low intensity correlations between their values in the four trials and geographical location (altitude, latitude, longitude and ecophysiological latitude) of the tested seed sources.

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Sažetak

Cilj istraživannja bila je analiza reakcije 33 sjemenske sastojine obične smreke, iz područja rumunjskih Karpata, s obzirom na rast i karakteristike drva na pokusnim plohama smještenim unutar (Breþcu i Gurghiu) i izvan njihove prirodne rasprostranjenosti (Avrig i Câmpina) (sl. 1). Trideset godina nakon sadnje izvršena su mjerenja sljedećih značajki: ukupna visina (UV), prosječni volumen po stablu (PV/S), radijalni prirast (RP), postotak kasnog drva (PKD) i standardna gustoća drva (SGD). Utvrđeni su i koeficijenti korelacije između ispitanih pokusnih ploha i zemljopisnih obilježja sastojina. ANOVA je otkrila značajne ($P < 0.01$) razlike između biljnih zajednica svih pokusnih ploha, uz iznimku radijalnog prirasta (RP), što ukazuje na činjenicu da je moguće izvršiti izbor na razini sjemenske sastojine. S obzirom na ukupnu visinu (UV) i radijalni prirast (RP), utvrđeno je da se najvrjednije sastojine općenito nalaze na istočnim i zapadnim Karpatima, iako su velike vrijednosti radijalnog prirasta (RP) i postotka kasnog drva (PKD) uglavnom zabilježene kod sastojina na istočnim Karpatima. Vrijednosti radijalnog prirasta (RP), postotka kasnog drva (PKD) (sl. 2) i prosječnog volumena po stablu (PV/S) bile su niže na pokusnim plohama smještenim izvan prirodnih staništa, dok su vrijednosti ukupne visine (UV) i standardne gustoće drva (SGD) bile više. Analiza lokacije također je pokazala veliku važnost interakcije između biljne zajednice i okoliša za sve parametre (osim SGD). Iste biološke zajednice različito reagiraju na promjene uvjeta u okolišu. Prema rezultatima ovoga rada moguće je preporučiti određene biljne zajednice, s tim da se reprodukcijski materijal iz ovih izvora može koristiti samo u ekološkim uvjetima koji su slični onima gdje je provedeno ispitivanje. Utvrđeno je da je standardna provenijencija prema IUFRO-u (Moldoviţa) najbolja biljna zajednica za provođenje svih ispitivanja.

Tablica 1 prikazuje fizičko-geografske i klimatske uvjete na 4 pokusne plohe, tablica 2 prikazuje srednje vrijednosti, koeficijente varijacije i amplituda varijacije za sve analizirane parametre, u svim eksperimentima. Rezultati ANOVA-e za sve lokacije i kombinacije sve četiri lokacije prikazani su u tablici 3 i 4. Tablica 5 predstavlja rezultate Pearsonove korelacije između analiziranih parametara i zemljopisnih obilježja sastojina iz kojih dolazi sjeme.

KLJUČNE RIJEČI: kontrolne pokusne plohe, obična smreka, kvantitativna obilježja, radijalni prirast, gustoća drva.