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VARIATION IN WOOD DENSITY AMONG *PICEA ABIES* PROVENANCES IN THE ROMANIAN CARPATHIANS

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Abstract: *Wood density is an intricate trait that encapsulates water transport, growth, and productivity. It is probably the most used parameter to deduce wood quality. In this study, the wood density of 81 European provenances of Norway spruce tested in three provenance trials from the Romanian Carpathians was analysed and compared at 49 years after planting. We also analysed the correlations between wood density and the provenances' geographic coordinates, as well as other traits, such as diameter at breast height, total height, and survival rate. For the genetic variance analysis of the wood density in each provenance trial and across sites, linear mixed models were used. Significant differences between the Norway spruce provenances regarding wood density were found only in the Dorna Candrenilor trial, where the mean wood density per provenance had values ranging from 0.311 ± 0.030 g/cm^3 to 0.356 ± 0.019 g/cm^3. No significant correlations between wood density and the provenances' geographic coordinates were found. Negative correlations were found between wood density and the other traits analysed. Provenances with good performances in provenance trials could be used in assisted migration.*

Key words: *Norway spruce, provenances, conventional wood density, provenance trials, genetic variance.*

1. Introduction

Tree breeding programs have been focused on increasing the growth rate, thus reducing the rotation age of the planted tree species [7]. A reduced rotation age increases the juvenile wood proportion, which is of lower density and lower value for the end products [34]. For coniferous species, larger tree rings result in a lower tree density [10, 12]. Although wood density is associated with slower

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growth, it is also correlated with a longer lifespan [6]. In Central Europe, while trees and stands exhibited higher growth rates, a reduction of 8-12% has been registered for the wood density since 1900 [24].

Defined as the mass of wood per unit volume [39], wood density is a multiplex trait, encapsulating water transport, growth and productivity [6]. It is probably the most used parameter to deduce wood quality [19, 33] because stem stability, carbon sequestration, and the decomposition rates are all linked with wood density [36]. Tree ring wood density is closely related to timber strength [27], hardness, and abrasiveness [5, 25]. As such, a tree ring wood density that is reduced could lead to a loss of mechanical stability [3] against, say, breakage by wind or snow [37]. Also, reduced stress from drought occurrences could be indicated by a decrease in tree ring wood density [36]. Wood density declines from the pit outward until it reaches a minimum at approximately rings 10-20 [27]. After that, wood density increases with each following ring [16].

There are many studies on wood density in provenance trials [22, 28, 35] , but few have been done at more mature ages [32, 38]. Previous studies in Romania, concerning the wood density of Norway spruce provenances have been done at the age of 30, in trials comprised of only seed sources from the Romanian Carpathians [29].

Norway spruce is among the most important coniferous species in Europe. Its distribution area of around 30 million hectares represents 38% of the total coniferous species area [17]. It has been highly extended beyond its natural range, the extended area representing more than 20% of its distribution area [17].

In Romania, Norway spruce has an area of 1.37 million ha (21% of the total forest area) [1], from which around 360,000 ha represent its extension beyond its natural range [30].

This study aimed (1) to analyse and compare the wood density of 81 provenances of Norway spruce from three provenance trials from the Eastern, Southern and Western Romanian Carpathians at 49 years after planting, and (2) to analyse the relationships between wood density and the provenances' geographic coordinates and other traits.

2. Materials and Methods

The three provenance trials in our study were established in 1972 [21], in the Eastern, Southern and Western Romanian Carpathians: Dorna Candrenilor, Zarnesti, and Turda, respectively. The Dorna Candrenilor and the Turda trials are located in the vegetation zone of Norway spruce, while the Zarnesti trial is located in the vegetation zone of mixed beech and coniferous species.

Eighty-one provenances were tested, 10 Romanian and the rest from 12 other European countries. The natural and planted distribution of Norway spruce is well represented/covered by the tested provenances, their northern latitudes ranging from 41.6 to 63.28° and their eastern longitudes ranging from 6.03 to 34.62°. Regarding the provenances' altitude of origin, it is between 20 and 2,000 m. The positions of the provenances and the trials are represented in Figure 1.

The provenance trials' design is a randomised complete block, with 16 trees per provenance at 2 x 2 m spacing and three blocks. Four trees were randomly selected for each provenance in each block, where possible. One core was extracted from each selected tree on the slope line to avoid tension and compression wood. The wood samples were extracted in 2020, at 49 years, almost half of the rotation age of the species in Romania.

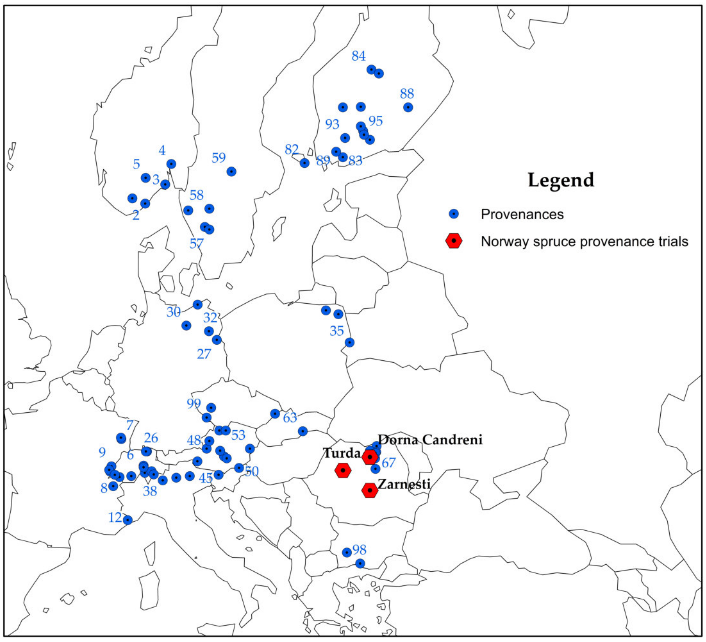

Fig. 1. *The positions of the Norway spruce provenance trials and of the provenances; the dots and numbers represent the provenances, while the red hexagons represent the trials*

Conventional wood density, expressed in g/cm^3, was calculated for each wood core using the formula (Eq. (1)) proposed by Dumitriu-Tătăranu et al. [11]:

$$\rho_c = \frac{1}{\frac{M_{max}}{M_0} - 1 + \frac{1}{\rho_{ml}}} \qquad (1)$$

where:

ρ_c is the conventional density [g/cm^3];

M_{max} - the weight of saturated sample [g];

M_o – the weight of dried sample [g];

ρ_{ml} – the wood density [1.53 g/cm^3].

To analyse the correlations between wood density and the geographic coordinates of the provenances and other traits, previously published data has been used [2].

The genetic variance analysis of the wood density was performed for each trial site and across sites.

For each trial, a linear mixed model was used (Equation (2)), considering provenance as a random effect and block as a fixed one:

$$Y_{ijk} = \mu + P_i + B_j + e_{ijk} \qquad (2)$$

where:

μ – the general mean;

P_i – the random effect of the *ith* provenance;

B_j – the fixed effect of the *jth* block;

e_{ijk} – the error term associated with *ijk* trees.

The following linear mixed model (Equation (3)) was used for the analysis across sites [20]:

$$Y_{ijk} = \mu + P_i + B_j + S_k + P_i \cdot S_k + e_{ijkl} \quad (3)$$

where:

- μ – the general mean;
- P_i – the random effect of the *ith* provenance;
- B_j – the fixed effect of the *jth* block;
- S_k – the site effect [measure unit];
- P_i x S_k – the provenance x site interaction;
- e_{ijkl} – the error term associated with *ijkl* trees.

For computing and testing the linear mixed effects models, the lmerTest R package [18] was used in the R software [26].

The Pearson coefficient was used to assess the correlations between wood density and the provenances' geographic coordinates and diameter at breast height, total and pruned height, and the survival rate.

3. Results and Discussion

In this study, 81 Norway spruce provenances from Romania and from 12 other countries were analysed and compared regarding their wood density at 49 years after planting in three comparative trials from Romania.

Table 1 presents the results of the genetic variance analysis for the wood density of Norway spruce provenances for each trial at 49 years.

Table 1

The genetic variance analysis for the wood density of Norway spruce provenances for each trial at 49 years

	Dorna Candrenilor	Zărnești	Turda
LRTp	7.8212 **	0.0651 ns	1.5768 ns
Vp	0.00003	0.000003	0.0002
Vr	0.0063	0.0007	0.0010
MS b	0.0006 ns	0.0031*	0.00001 ns
Mean ± SD	0.331 ± 0.026	0.341 ± 0.027	0.337 ± 0.031

Note: *, **, *** - Significant at 5%, 1% and 0.1%, respectively; ns - nonsignificant; LRTp - likelihood ratio test for provenance random effect; Vp - variance for provenance random effect; Vr - residual variance; MS B - mean squares for block effect.

Significant differences between the Norway spruce provenances regarding wood density were found only in the Dorna Candrenilor trial (Figure 2). The mean wood density per provenance ranged from 0.311 ± 0.030 g/cm^3, provenance 89-Pielisjarvi, from Northern Europe, to 0.356 ± 0.019 g/cm^3, provenance 56-Anfasterod, from Northern Europe, which were 6.04% lower and 7.55% higher, respectively, than the site mean.

In the Turda trial, the provenances had a mean wood density with values between 0.309 ± 0.044 g/cm^3, provenance 93-Urjala, from Northern Europe, and 0.360 ± 0.051 g/cm^3, provenance 26-Winterthur, from Central Alps, which were 8.39%

lower and 6.75% higher, respectively, than the site mean.

The mean wood density of the provenances in the Zarnesti trial was between 0.320 ± 0.018 g/cm^3, provenance 58- Aspas, from Northern Europe, and 0.365 ± 0.026 g/cm^3, provenance 68-Breaza, from the Romanian Carpathians, which were 6.26% lower and 6.91% higher, respectively, than the site mean.

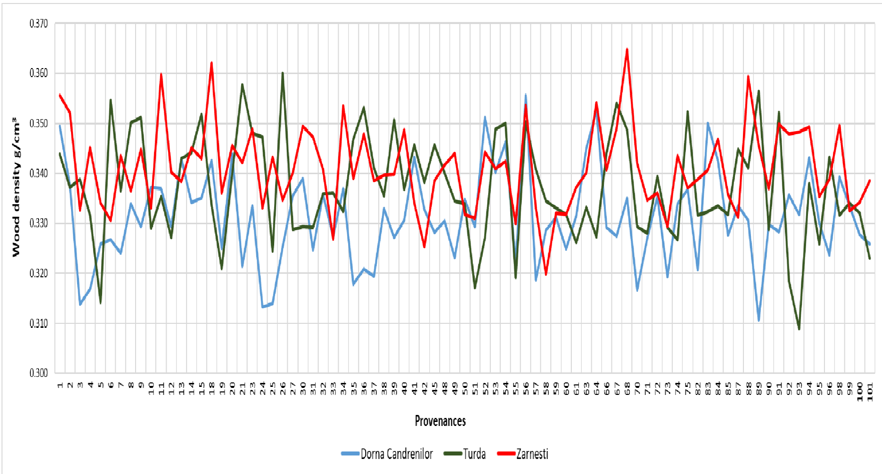

Fig. 2. *The variation of the wood density of Norway spruce provenances in the Romanian provenance trials at 49 years*

Analysing the genetic variance across trials, the provenance effect was not significant, but with a p = 0.0503 (Table 2). The provenance x trial effect was not significant, indicating that the provenances had stable performance regarding wood density. The differences between trials were significant. In other Norway spruce provenance trials from Romania, the provenance effect was significant, but the provenance x trial effect was also not significant [29].

Table 2

The genetic variance analysis for the wood density of Norway spruce provenances for all trials at 49 years

LRTp	LRTpxT	Vp	V pxT	Vr	MS T	MS b
3.8299 ns	0.5746 ns	0.00001	0.00001	0.00096	0.0068***	0.0012 ns

Note: *, **, *** - Significant at 5%, 1% and 0.1%, respectively; ns - nonsignificant; LRTp - likelihood ratio test for provenance random effect; LRTpxT - likelihood ratio test for provenance x trial random effect; Vp - variance for provenance random effect; VpxT - variance for provenance x trial random effect; Vr - residual variance; MS T - mean squares for trial effect; MS b - mean squares for block effect.

A low wood density is found in species such as fir and spruce, which are heartwood-free species, with values of 0.358-0.378 g/cm^3 [13, 23]. In our study, the mean values for the trials were lower, the highest value obtained was in the

Zarnesti trial, 0.341 ± 0.027 g/cm^3. The lowest one was obtained in the Dorna Candrenilor trial, 0.331 ± 0.026 g/cm^3, which was 2.85% lower than the one obtained in the Zarnesti trial (Figure 3). Șofletea et al. [29] obtained similar mean values for the wood density of two other Norway spruce provenance trials from Romania, 0.348 and 0.329 g/cm^3, respectively.

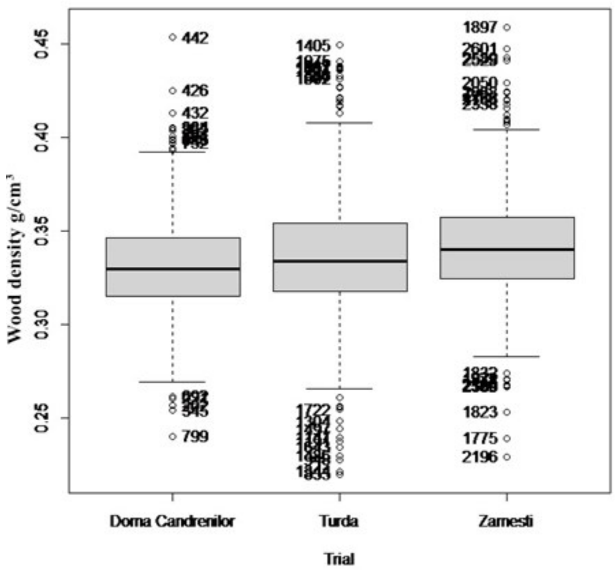

Fig. 3. *The variation of the wood density of Norway spruce provenances in the three provenance trials at 49 years*

Provenance 56-Anfasterod, from Northern Europe, had high wood density in all three provenance trials, with values ranging from 0.350 to 0.356 g/cm^3 in the Turda and Dorna Candrenilor trials, respectively.

On the other hand, provenance 55-Munkahus, also from Northern Europe, had a low wood density in all three provenance trials, with values ranging from 0.319 to 0.330 g/cm^3 in the Turda and Zarnesti trials, respectively.

From the Romanian provenances, 64-Gheorghieni and 67-Frasin had good performance in two out of the three provenance trials, Dorna Candrenilor and Zarnesti, and Turda and Zarnesti, respectively. Provenance 68-Breaza had good performance in the Zarnesti trial and was above average in the other two provenance trials.

No significant correlation was found between wood density and the geographic coordinates of the provenances. Regarding the other traits analysed, the correlations were all negative and very weak or weak, with the Pearson coefficients being -0.183, -0.309, -0.383, and -0.375 for survival rate, diameter at breast height, and total and pruned height, respectively (Table 3).

Similar results have been previously published [8, 10, 12, 14, 15, 31, 40]. In the study by Skrøppa et al. [28], at the juvenile stage, in Norway, the correlations between wood density and height growth were moderate to strong negative. In two

Norway spruce half-sib comparative trials from Romania, at 25 years, the correlations of conventional wood density with height and breast height diameter were also negative [4].

Table 3

Correlations between wood density and the provenances' geographic coordinates and other traits

	Diameter at breast height	Total height	Pruned height	Latitude	Longitude	Survival rate
Wood density	-0.309***	-0.383***	-0.376***	-0.056 ns	-0.036 ns	-0.183**

Note: *, **, *** - Significant at 5%, 1% and 0.1%, respectively; ns - nonsignificant.

It has been demonstrated that wood density has an important role in the mechanical stability of the trees, in wood strength and energy content – both calorific and thermal values, as well as in carbon content and storage [9, 24, 36]. By selecting the provenances with the highest wood density, all these properties could be improved.

4. Conclusions

In this study, the wood density of 81 Norway spruce provenances from Romania and 12 other countries was analysed and compared at 49 years after planting in three comparative trials from Romania. Significant differences between the Norway spruce provenances regarding wood density were found only in the Dorna Candrenilor trial. Analysing the genetic variance across trials, the provenance effect and the provenance x trial effects were not significant, indicating that the provenances had stable performances in terms of wood density.

Negative correlations were found between wood density and survival rate, diameter at breast height, and total and pruned height, respectively. The stability of the stand can thus be increased by reducing the competition between trees.

Selecting provenances with higher wood density would increase the stability of the stand, wood strength, energy content, and carbon sequestration.

Provenance studies need to be continued since the provenance trials were only 49 years old, half of the exploitation age of Norway spruce in Romania.

Acknowledgements

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