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Valuation of the Economic Benefits from Using Genetically Improved Forest Reproductive Materials in Afforestation

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Abstract: The research objective was to demonstrate the economic impact of using, in afforestation, forest reproductive materials (FRMs) obtained from seed trees selected in the most valuable Norway spruce populations of the FGRs' (forest genetic resources') category. The values obtained for the main growth traits (diameter at breast height (Dbh), tree height (Th), and tree volume (Tv)), both in the FGR and in the closest population (with the same age and growth in similar environmental conditions), were compared. Three comparative trials were analyzed, each belonging to different breeding levels: Open-pollinated (Breţcu, 40 years old), half-sib (Măneciu, 25 years), and full-sib (Comandău, 23 years). The difference in volume/hectare between the FGR and an unimproved neighbor population was economically quantified (€), based on the average price per cubic meter (m^3) of spruce wood in Romania; the profit at the end of the rotation period (110 years) was projected taking into account the genetic gain that will result from the use of FRM collected from the FGRs. The average FGR growth results were superior to the unimproved neighbor populations, with 8%–13%, 14%–25%, and 26%–79% for Dbh, Th, and volume/ha, respectively, and the differences increased if the best 10% seed trees of the trials were used. For Th, a five times higher family mean heritability was registered for the *pendula* trees (compared to *pyramidalis*) in the half-sib trial, while in the full-sib experiment, the *pendula* trees (both full and half *pendula*) again registered higher heritability, but for Dbh, which recommends the *pendula* selection for different traits in the two trials. These results have led to a rate of profitability between 540 and 3366 €/ha, a value that is predicted to increase until the end of the rotation period, when the genetic gain could generate a profit of 7560 €/ha.

Keywords: biodiversity; breeding strategy; economic analysis; forest values; genetic gain; heritability

1. Introduction

Forest ecosystems, managed properly, offer important resources for direct economic goods (e.g., timber) [1], additional wooden products, numerous nontimber forest products (fruits, oils, medicinal plants, etc.), and support other economic activities, for instance, agriculture and fisheries [2]. The relationship between forest ecosystems and the forest industry requires a balance between the needs of industry and the development of natural ecosystems [3]. The continuously increasing demand for wood requires the identification of solutions to increase the production of wood/ha. This could be achieved, among other methods, by using genetically improved forest reproductive material (FRM) in plantations [4–6]. Additionally, increasingly climatic disturbances affect trees' resistance and

their physiological processes [7]. The selection of an adapted population and seed trees inside them represents a chance to increase forest stability and productivity over the next generations of breeding programs by using FRM from these populations [8–15]. In the last 100 years, artificial regeneration has continually increased [16,17] and numerous allochthonous species have been used [18–23].

Identification, conservation, and management strategies for forest genetic resources (FGRs) are of high interest for geneticists [24]. The conservation of FGRs is important for maintaining genetic diversity in large populations (minimum 500 seed trees/population), preserving specific adaptations in marginal/peripheral populations (minimum 50 seed trees/population), and conserving rare species in relict populations (minimum 15 seed trees/population) [25]. The dynamic FGR conservation strategy [24] was implemented in Romania, as well as 32 other European countries. As sequencing of the Norway spruce genome is complete [26], the genomic selection can be combined with traditional breeding programs, constituting a giant leap in tree breeding [27,28].

The objective of the present paper was to demonstrate the economic importance of using, in afforestation, the FRM obtained from seed trees selected in the most valuable populations, within the FGR's category. For a very important species of the Romanian [29] and European forests [30,31], Norway spruce (*Picea abies*), we compared the values obtained for the main growth traits (diameter at breast height (Dbh), tree height (Th), and tree volume (Tv)) both in the FGR, and in the closest unimproved population with approximately the same age and benefiting from similar environmental conditions. Additionally, the average values recorded in the FGR were compared to the average values at the country level. Differences in trees volume/hectare between FGRs and the closest unimproved populations were transformed into euros (€), taking into account the average price per cubic meter (m^3) of spruce wood in Romania. Additionally, the profit at the end of the rotation period (110 years) was projected based on the genetic gain that would result from the use of FRM collected from the FGRs.

2. Materials and Methods

Three comparative trials from different breeding levels were investigated: One open-pollinated (Brețcu, 40 years), one half-sib (Măneciu, 25 years), and one full-sib (Comandău, 23 years). Data for the nearest similar stands (same ages and similar environmental conditions) were also taken.

The Brețcu trial was established in the ecological optimum for Norway spruce, in the Curvature Carpathians region (i.e., the inner zone of the Carpathian chain), at a 1100-m average altitude (a.s.l.), at 45°58′ N latitude and 26°24′ E longitude, in a mountainous mixed-stand vegetation forest. The slope has a northeast exposition with a 15° inclination. The soil is typical eutricambosoil. The average annual temperature was 4.8 °C, and the sum of the annual precipitation was 830 mm [32]. In this trial, 33 seed stand provenances (Figure 1) were tested in an incomplete balanced square-grid design, with three replications and 49 seedlings/plot, planted with 2 m by 2 m spacing. Every provenance was composed of progenies obtained from bulked seeds harvested from 10 trees [33]. In each replication, 10 trees/provenance were randomly chosen and the diameter at breast height (Dbh) and tree height (Th) were measured. At the office, tree volume (Tv) was determined using the volume regression equation method [34].

The Măneciu comparative trial was also located in the Curvature Carpathians, but on the outside zone of the Carpathian chain, in a superior productivity forest type. The soil is also typical eutricambosoil, but on a slope with southern exposition, 10° inclination, at an altitude of 820 m, 45°25′ N latitude and 25°57′ E longitude. The average annual temperature here is 6.0 °C, and the sum of the annual precipitation is 880 mm. In this trial, the experimental design was incompletely balanced, with four replications and 4–10 seedlings per plot planted with 2 m by 2 m spacing, in which each of the eight provenances (yellow circles, in Figure 1) were represented by descendants obtained from seeds harvested from three *pendula* and three normal crown spruce trees, resulting in a total number of 24 families for each of the two crown forms [35]. The Măneciu trial was installed in order to test the behavior of the narrow-crown Norway spruce ideotype (*pendula* form), which was believed to be

stronger than the normal spruce crown (*pyramidalis* variety) in the face of harmful action of storms and heavy snows [36,37].
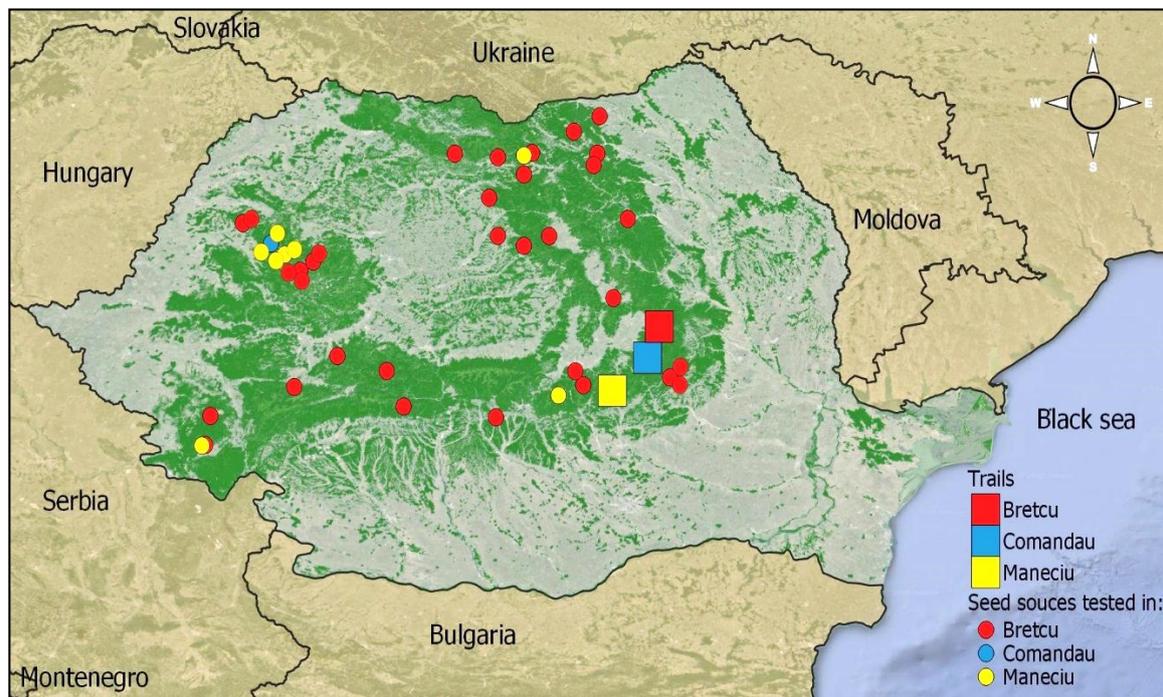

Figure 1. Location of the trials and the tested population's origin.

The Comandău comparative trial was also established in the ecological optimum for Norway spruce, in the Curvature Carpathians region (inner zone of the Carpathian chain), at a 1020-m average altitude (a.s.l.), 45°42′ N latitude and 26°18′ E longitude, in mountainous mixed-stand vegetation forest of superior productivity. The slope has a north exposition, and a 16° inclination; the soil is typical districambosoil. The average annual temperature is 4.8 °C and the sum of the annual precipitation is 880 mm. The design was incompletely balanced, with 4 replications and 3–9 seedlings per split plot, planted at 2.5 by 2.5 m spacing, in which the descendants of six families (three *pendula* and three *pyramidalis*) obtained through open or controlled pollinated in the Stâna de Vale population (the blue circle, in Figure 1) were present [7]. This trial was installed in order to compare the *pendula* trees with the normal crown form trees and also the adaptability of the hybrids of the two forms of Norway spruce.

The economic importance of this FGR, conserved ex situ, regarding the utilization of FRM harvested from these were analyzed. The data for Dbh, Th, and Tv were used to compare the results of the three FGR to the normal local population, and to the national results of Norway spruce of the same ages. The narrow-sense individual heritability (h_i^2), half-sib family mean heritability (h_F^2), and genetic gain were determined in the half–sib trial (Măneciu) in order to express genetic inheritance and also the supplementary gain resulted by the selection of seed trees from the most valuable 10% trees/families of the trial. Heritability was calculated as [38]:

$$h_i^2 = \frac{\sigma_A^2}{\sigma_{Ph1}^2} = \frac{4\sigma_f^2}{\sigma_f^2 + \sigma_{fxr}^2 + \sigma_e^2} \quad h_F^2 = \frac{\sigma_A^2}{\sigma_{Ph2}^2} = \frac{\sigma_f^2}{\sigma_f^2 + \frac{\sigma_{fxr}^2}{r} + \frac{\sigma_e^2}{rxn}}$$

where σ_A^2 is the additive genetic variance, σ_{Ph}^2 is the phenotypic variance, σ_f^2 is the family variance, σ_{fxr}^2 is the family × replication interaction variance, σ_e^2 is the residual variance, r is the number of replications, and n is the number of seedlings/plot. In the experiment with half–sib families, $\sigma_A^2 = 4\sigma_f^2$.

For the Comandău full-sib trial, heritability was calculated using the following formula:

$$h_A^2 = \frac{2\sigma_{GCA}^2}{2\sigma_{GCA}^2 + \sigma_{SCA}^2 + \sigma_M^2 + \sigma_R^2 + \frac{\sigma_e^2}{k}}$$

where σ_{GCA}^2 and σ_{SCA}^2 are the variances of the general and specific combining abilities; and σ_M^2, σ_R^2, and σ_e^2 are the variances attributed to maternal, reciprocal, and environmental effects (error); and k is the number of replications [37].

For the half-sib and full-sib trials, the genetic gain was calculated at 10% selection intensity, as [39]:

$$\Delta G = i \times h^2 \times \sigma_P$$

where i is the selection intensity, h^2 is the heritability, and σ_P is the phenotypic standard deviation.

For the Brețcu trial, seeds were bulked inside the provenance without preserving the maternal identity, so heritability (and implicitly the genetic gain) could not be calculated.

The differences between the average volumes of trees within the three FGRs and the neighboring unimproved populations were transformed into euros, taking into account the average price per cubic meter of wood, fixed by the market price at the last auction organized by the Romanian National Forest Administrator (Romsilva) [40]. In the areas where the three FGRs are established, Norway spruce regeneration is produced artificially through plantations, and price differences in the purchase of seeds are negligible. No additional costs are required for seed procurement (or seedlings), getting seedlings, land preparation, and planting, compared to the utilization of unimproved FRM. In Romania, the average price of 1000 seedlings (aged 2 years) is about 100 €.

The data were statistically processed using breedR (a genetic package of the R program) [41,42]. The growth model until the end of the rotation period (110 years) was predicted using the Chapman–Richards function [43] and the genetic gain was incorporated in the equation [44]:

$$\frac{d}{dt}W = \left(A^{1-m} \times W^m - W\right) \times K,$$

where *W* is a dimensional parameter (Dbh, Th, and Tv); *A* is an asymptotic parameter, a maximum value of the growth variable; and *m* and *K* are the parameters associated with catabolism and allometry (*K* indicates a change in the growth rate while *m* indicates changes in the inflection point of the growth curve, respectively, the slope of growth). The growth function was computed using the "robustbase" package in R [42] for the time series of 110 years. Data from Romanian yield tables [34] corresponding to the production class curve were used to continue the data from the trials. Measurements in trails were fitted with data from the yield tables, constructing a prediction of the growth. The uncertainties and errors associated with the grow curve projected are similar with the ones presented in the yield tables [34]. Data for the unimproved neighbor populations were collected and used for comparation.

3. Results

3.1. Brețcu Trial

The results obtained by the descendants of the 33 provenances of Norway spruce in the Brețcu comparative trial, at 40 years, demonstrated significantly better growth compared to the nearest population that developed in the same plot and in similar environmental conditions. The trial averages were superior, with 13% Dbh, 14% Th, and 26% volume/ha (Table 1).

Table 1. Results of growth traits (± standard deviation) registered in the Breţcu trial, the average of the neighbor unimproved population, and the national mean volume/ha of Norway spruce, at age 40.

Breţcu Trial	Breast Height Diameter (cm)	Trees Height (m)	Trees Volume (m³)	Volume/Hectare (m³/ha)
Average Breţcu	24.8 ± 5.1	21.6 ± 2.3	0.518 ± 0.2	474
Best 10% provenances	26.6 ± 5.2	22.7 ± 2.3	0.617 ± 0.2	-
Best 10% trees	33.9 ± 2.1	25.3 ± 0.8	0.983 ± 0.1	-
Local provenance (in trial)	24.0 ± 5.3	21.6 ± 2.3	0.509 ± 0.2	-
IUFRO standard provenance	24.5 ± 5.2	21.8 ± 2.3	0.509 ± 0.2	-
Nearest population	22.0 ± 4.7	19.0 ± 2.2	0.345 ± 0.1	375
National average volume/ha*	-	-	-	342

Note: * Sources: [45].

If we compare the results obtained by the best 10% provenances and the most valuable 10% trees in the Breţcu trial with the nearest unimproved population, the differences are much higher and in favor of the trial trees. Within this trial, the provenance closest to the experiment (Comandău) and the I.U.F.R.O. standard provenance (Moldoviţa) registered a 2% smaller volume compared to the trial average, but when compared with the best performing provenance (Gurghiu), these two are 23% smaller (Table 1).

In Romania, the average price per cubic meter of Norway spruce wood assortment of 15–30 cm in diameter is approximatively 34 € [40]. The economic impact of the utilization of forest reproductive materials from Breţcu FGR translates into a minimum profit of 3366 €/ha ($474 - 375 = 99 \times 34 = 3366$), indicating that it is possible to increase the average volume/ha of the trial to the local population mean volume/ha when the best 10% trees are selected as seed trees.

3.2. Măneciu Trial

In the Măneciu half-sib comparative trial, the same average values (Dbh = 17.0 cm, Th = 16.2 m, Tv = 0.21 m³) were obtained both for the *pendula* and *pyramidalis* families, at 25 years. Inside the *pendula* form, the most performed 10% families registered an 11% superiority for Tv compared to the trial average, while, at the individual tree level, the average Tv of the best 10% *pendula* trees (96 trees, which will be chosen as seed trees) exceeded with 98% the trial average.

The nearest Norway spruce stand with the same age and growth in similar environmental conditions presents mean values for Dbh, Th, and Tv that are inferior by 12%, 20%, and 44%, respectively, than the Măneciu average trial. Therefore, the average Tv of the seed trees is 3.5 times larger than the unimproved local population. However, to avoid overestimation, the economic profitability of using FRM from FGRs was calculated using the Măneciu Tv average.

In Romania, the average price per cubic meter of Norway spruce wood assortment of the 10–25 cm diameter is approximatively 25 € [40]. The economic impact of the utilization of forest reproductive materials from Măneciu FGR translates into a minimum profit of 2775 €/ha ($252 - 141 = 111 \times 25 = 2775$), reporting the average volume/ha of the trial to the mean volume/ha of the nearest unimproved population. It is possible to increase this by selecting the best 10% trees as seed trees.

3.3. Heritability and Genetic Gain in the Măneciu Trial

In the Măneciu trial, the narrow-sense individual heritability ranged between 0.01 and 0.32. The highest inheritance rate for mass selection was registered for Th, especially for the *pyramidalis* trees. For the family selection, the heritability ranged between 0.13 and 0.67, with the highest inheritance rate also registered for Th, but this time the *pendula* trees were noticed (Table 2).

For all trees, and also separately for *pendula* and *pyramidalis* trees, superior genetic gains were registered for Th when the mass selection was applied. For the family selection, different strategies must be applied: The selection for Th, once again, for *pendula*, while for *pyramidalis* trees, the genetic gain values were higher for Dbh. For the *pendula* trees, the genetic gain was higher at the family

level, while for *pyramidalis* trees, the mass selection strategy seems to be more appropriate (Table 2). These data may indicate a selection strategy in favor of the best *pendula* trees from the top populations regarding Th because of the high inheritance rate (Figure 2).

Table 2. Results of growth traits (± standard deviation), heritability, and genetic gain in the Măneciu trial.

Măneciu Trial	Breast Height Diameter	Tree Height	Tree Volume
All trees			
Best 10% trees*	22.2 ± 2.4	19.1 ± 0.6	0.382 ± 0.1
Trial average*	17.0 ± 3.6	16.2 ± 2.1	0.210 ± 0.1
Heritability (i/F)	0.08/ 0.18	0.23/ 0.31	0.04/ 0.15
Genetic gain (i/F) (%)	15/ 13	25/ 22	13/ 21
***Pendula* trees**			
Best 10% trees*	22.0 ± 2.5	19.2 ± 0.7	0.377 ± 0.1
Average *pendula**	17.0 ± 3.7	16.2 ± 2.1	0.210 ± 0.1
Heritability (i/F)	0.02/ 0.15	0.23/ 0.67	0.01/ 0.18
Genetic gain (i/F) (%)	2/ 8	20/ 34	2/ 20
***Pyramidalis* trees**			
Best 10% trees*	22.4 ± 2.4	19.1 ± 0.6	0.387 ± 0.1
Average *pyramidalis**	17.0 ± 3.6	16.2 ± 2.1	0.210 ± 0.1
Heritability (i/F)	0.19/ 0.21	0.32/ 0.13	0.14/ 0.15
Genetic gain (i/F) (%)	22/ 19	31/ 6	25/ 23

Note: * The results are expressed in cm/ m/ m^3 for Dbh, Th, and Tv, respectively; (i/F = individual/ family). Genetic gain was calculated for the best 10% trees/families selected after Th.
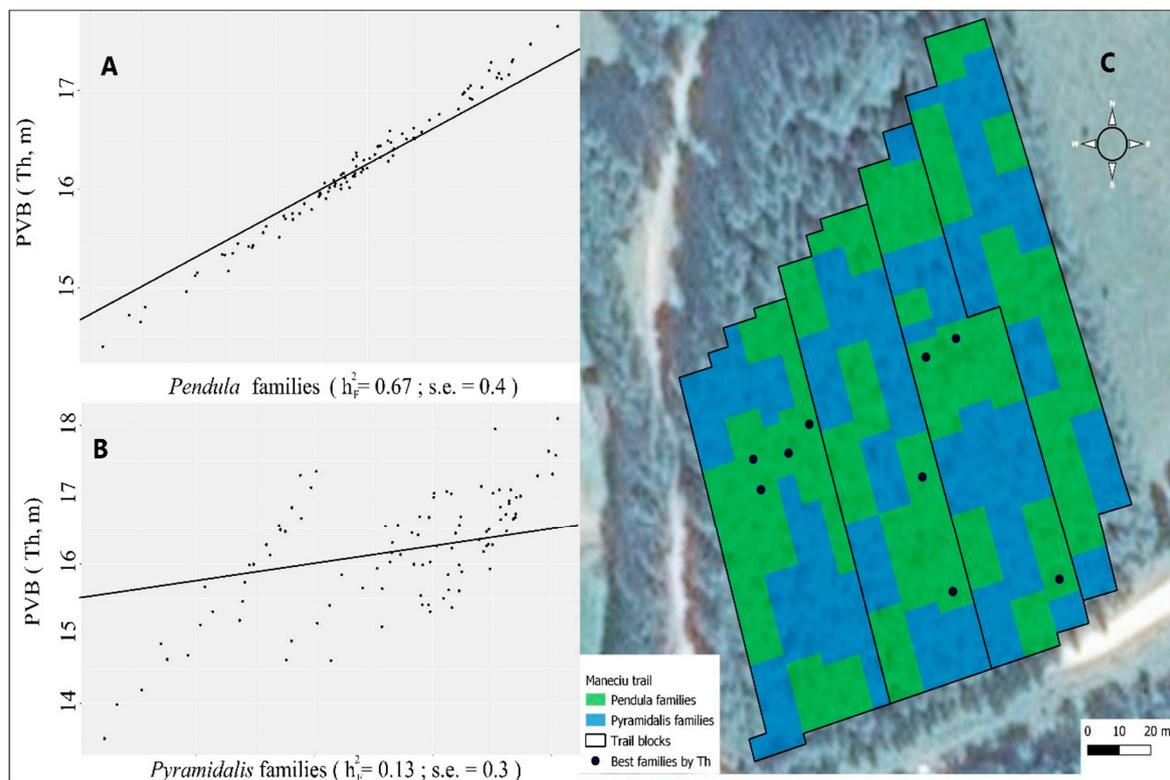

Figure 2. Predicted breeding values (PBVs) for *pendula* (**A**) and *pyramidalis* (**B**) families, according to Th, and the spatial distribution (**C**) of the two forms in the Măneciu trial. The most valuable *pendula* families are dotted.

The influence of the environmental conditions, expressed by the replication effect, is much stronger for the *pyramidalis* trees although the edge effect, at least, should have equally affected the two forms of Norway spruce and the forms were randomly distributed, as can be seen in Figure 2 (right side).

Among the best nine *pendula* families (for Th), four are grouped on a small surface in the first replication, which favors pollination between them.

3.4. Comandău Trial

The average Tv value of all 766 trees in the Comandău trial was 0.112 m^3; this was driven especially by the hybrids *pyramidalis* × *pendula* (0.14 m^3) (Figure 3). The first two trees, hybrids belonging to the combinations 41 × 7 and 40 × 6 (both *pyramidalis* × *pendula*), recorded values 3.4 times higher than the average of the experiment, showing pronounced positive somatic heterosis. The trial average value for Dbh was 14.1 cm, while for Th, the mean value was 11.6 m, with the best results found in the N×P hybrids. The best-performing 10% trees, which would be chosen as seed trees, registered a mean Tv 2.3 times larger than the trial average. Depending on the growth traits, the *pendula* ideotype registered poor results in the Comandău trial.
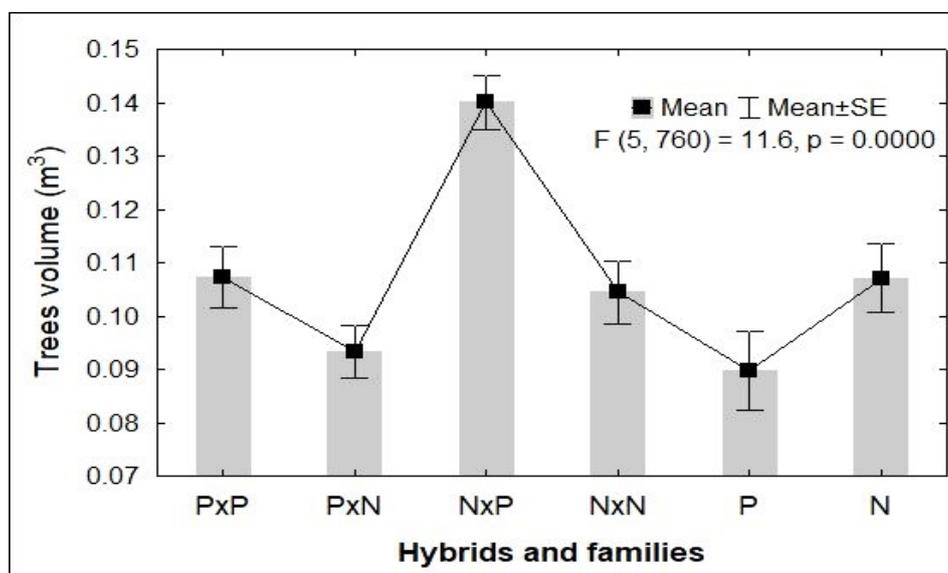

Figure 3. Mean Tv values of *pendula* (**P**) and normal (**N**, *pyramidalis*) crown forms and their hybrids.

In the nearest comparable population (same plot, age, and similar environmental conditions), the Norway spruce registered average values of 13 cm, 10.5 m, and 0.073 m^3, for Dbh, Th, and Tv, respectively. It is noted that the genetically improved population recorded a 53% higher Tv value. The volume per hectare in the Comandău test was 115 m^3, while in the unimproved neighbor population, where the planting scheme was denser (2 m by 2 m), the volume per hectare was 23% lower.

In Romania, the average price per cubic meter of the Norway spruce wood assortment 10–18 cm in diameter is approximatively 20 € [40]. The economic impact of the utilization of FRM from Comandău FGR translates into a minimum profit of 540 €/ha (115 − 88 = 27 × 20 = 540), reporting the average volume/ha of the trial to the local unimproved population mean value. It is possible to increase this by selecting the best 10% as seed trees.

3.5. Heritability and Genetic Gain in the Comandău Trial

In the Comandău full-sib trial, heritability and genetic gain were determined first for the hybrids, taking into account the general and specific combining abilities, maternal, reciprocal, and environmental effects. The heritability was zero for Th, while for Dbh and Tv, the heritability was 0.21 and 0.19, respectively. The genetic gain, calculated at a 10% selection intensity, was 24% for Dbh and only 1% for Tv. In this situation, the breeding strategy should focus on Dbh. Only for the narrow crown trees (with both parents' *pendula*), at the same selection intensity, the genetic gains were 13% for Dbh and 1% for

Tv. For a cross-*pendula* selection, with the unique goal of improving the growth traits, the breeding strategy will also follow the Dbh.

The narrow-sense individual heritability and genetic gain were also determined for the half-sib trees. In this case, the inheritance rate was 0.50, 0.24, and 0.49 for Dbh, Th, and Tv, respectively. The genetic gain at a 10% selection intensity was 46% for Dbh, 16% for Th, and 5% for Tv. However, this great genetic gain (especially for Dbh) resulted from the selection of the most valuable 15 trees, which would lead to a reduction of genetic diversity. The selection of the most valuable half-sib trees will be incorporated into the individual selection for the entire trial. A cross-*pendula* selection of the half-sib trees is indicated because the heritability values, 0.58, 0.18, and 0.61 for Dbh, Th, and Tv, respectively, were 4 to 8 times higher than for the *pyramidalis* trees.

3.6. Predicting the Growth Model and Profitability at the End of the Rotation Period

For the Breţcu open-pollinated trials as compared to the closest unimproved population, the results for growth traits at the age of 40 years, combined with the results recorded 10 years earlier, generated a prediction for the end of the rotation period (110 years) with a 28% superior volume/trees in favor of the Breţcu trial (Figure 4). Between the Măneciu half-sib trial and the closest unimproved population, the difference for the same trait was also favorable for the trial (with 31%), while as compared the Comandău full-sib experiment (with its unimproved neighbor population), the superiority of the trial was the lowest at 20% (Figure 4). This difference is likely to increase after the removal of the additional stems.
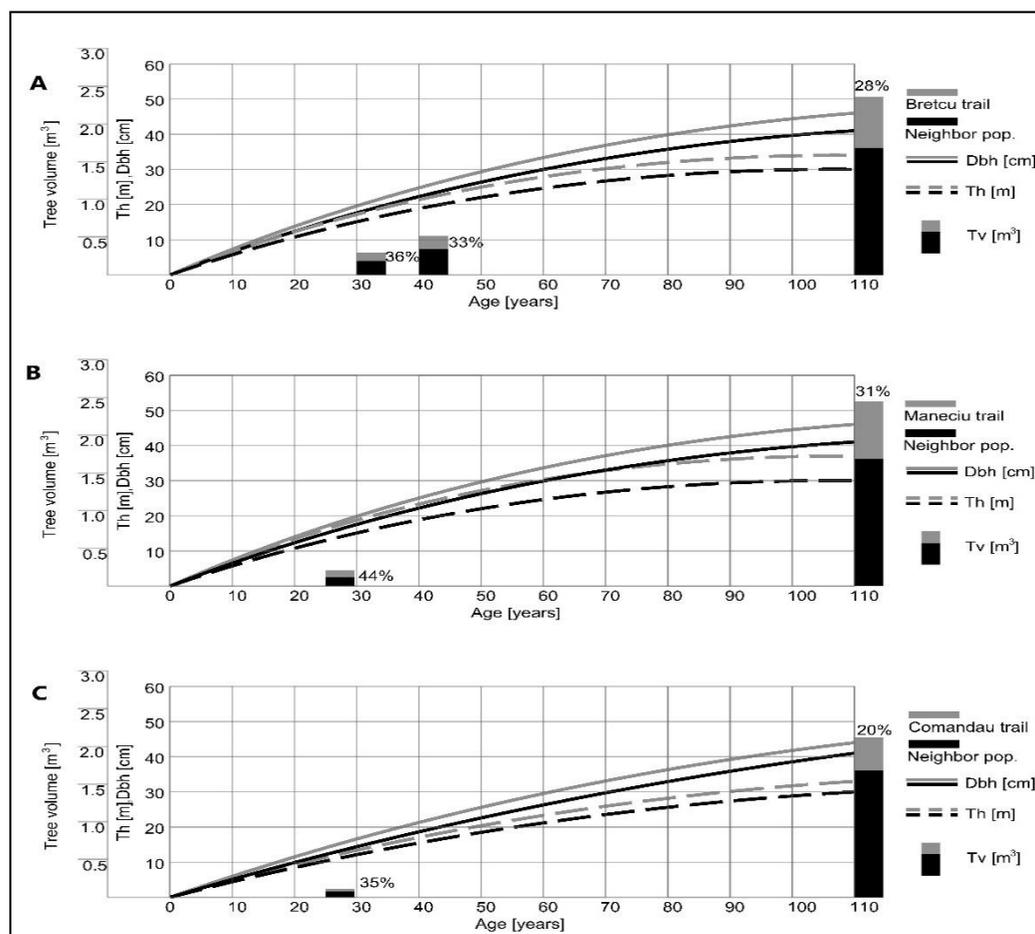

Figure 4. Prediction of the growth model development until the end of the rotation period for Breţcu (**A**), Măneciu (**B**) and Comandău (**C**) trials, compared to their unimproved neighboring populations.

At the end of the rotation period (trees age of 110 years old), as a product of the tree volume (Tv), an average minimum 20% profitability could occur, which will generate a minimum of 7560 €/ha profitability at an 168 m^3 difference in trees volume/ha, an average of 500 trees/ha at age 110 years [34], and an average price per cubic meter of Norway spruce wood assortment of 30–50 cm diameter of about 45 € [40].

4. Discussion

For forest owners, especially for those with small forest areas, the decision in using improved FRM for afforestation should be based on serious arguments, and careful data about FRM's superior impact on tree growth and wood quality, as well as increasing the resistance of forests to the harmful action of biotic and abiotic factors. A reliable estimate as to the minimum economic profit that could be obtained from the use of FRM from FGR would make their decision easier [44,46]. The results obtained here through comparative trials indicate a high rate of genetic inheritance in the offspring and thus, implicitly, an important genetic gain. This would suggest the use of FRM based on the performance both in the provenance region of the tested populations and also from the trial region where they performed [47]. Further, individual selections can be made in the trials by choosing the most valuable trees as seed trees, depending on the traits followed by the selection.

The tree volume/hectare registered in the Breţcu trial at age 40 years (36% of a rotation period) was 26% higher than the nearest unimproved population and the difference increased exponentially if we reported the most valuable 10% trees (which will be selected as seed trees) to the nearest population. Because the same actions are necessary for afforestation at the end of the rotation period as when using FRM from other seed sources, only small differences in seed costs appear in the economic balance and a minimum profit of 3366 €/ha is still expected. At the same time, the administrator of the Breţcu trial can sell seeds all over the country if they harvest separately for each provenance, selecting the most vigorous trees as seed trees.

In the Măneciu half-sib trial, the tree volume/hectare was 79% higher than the nearest unimproved population at 25 years (almost a quarter of a rotation period), and no differences in growth were registered for narrow and normal crown forms of Norway spruce. A minimum profit of 2775 €/ha is predicted and the seeds from the Măneciu trial can be used in 58% of the Romanian Carpathian provenance regions (if harvested separately for each provenance). However, the different reaction capacity of Norway spruce in changed environmental conditions reported in numerous studies [35,48–51] recommends extreme attention to the movement of FRM. The heritability and genetic gain indicate the possibility of adopting the *pendula* selection in order to promote this ideotype. A method that combines family selection with mass selection is recommended, by choosing the best *pendula* trees from the top populations regarding Th because of the high inheritance rate (especially at the family level (0.67)). At the same time, the highest genetic gain (34%) was shown for *pendula* trees (according Th), in the case of family selection. The fact that for *pendula* spruce trees, the genetic gain was higher at the family level than at the tree level, a situation opposite to that recorded for the *pyramidalis* variety, shows the superior ability of this ideotype to transmit the traits through descent.

The narrow-crowned Norway spruce ideotype (*pendula*) was not highlighted in the Comandău trial, as in other experiments of the same series [7]. However, its promotion is based on superior resistance to wind and snow [37,52]. In the Comandău trial, the volume/ha was, once again, higher than in the unimproved population (+ 31%). The very significant differences between the results recorded in the Comandău and Măneciu trials, though close in age, are due to the fact that the seedlings planted in Comandău were affected by late frosts in the nursery phase, and by 2018, 33% of the trees had developed presenting two or even three stems. In the same time, the growth of the Măneciu trial are stunning, with the Th exceeding the upper limit of the Romanian production tables for the 25-year spruce stands [35]. The genetic gain registered an impressive value for Dbh (24%) at a 10% selection intensity, a value very close to the maximum forecast in Europe [28,53].

In the full-sib trial, the genetic gain was highest for Dbh, while in the half-sib experiment, the same parameter registered a superior mean value for Th, which recommends a different selection strategy from the two trials, according to the trait that presented higher inheritance rates. Additionally, the selection in favor of the *pendula* trees will be a mass selection in the full-sib experiment and a combination of family and mass selection in the half-sib experiment. In the open-pollinated trial, in order to sell seeds all over the country, the selection strategy for Dbh or Th (or maybe Tv) was the same as in the half-sib experiment, by selecting the most vigorous trees as seed trees inside of all 33 provenances, and, after this selection stage, the harvesting and storage of seeds must be done separately in the provenances.

These results led to a rate of profitability, at present, of between 540 and 3366 €/ha, a value that is predicted to increase until the end of the rotation period, at which point the genetic gain will generate a profit of at least 7560 €/ha. The lowest economic impact (20% in Tv) is predicted for the Comandău full-sib experiment, but it is possible that the difference with the neighboring unimproved population grew until the end of the rotation period because the additional stems that affected 33% of the trees were removed. In Europe, previous research showed a 20% higher productivity in Norway spruce stands established with seedlings obtained from seed orchards, compared to the productivity of unimproved neighboring stands, and the difference increased in the third generation of selection by up to 35% [28,46,53]. A minimum 20% profitability benefit that can be increased to 28%–31% (according to the Măneciu and Brețcu tests) was predicted from our research at the end of the rotation period. We modeled different Chapman–Richard growth functions based on the trials and nearest unimproved populations, and a trend developed. However, because we did not have any trial that reached the age of 110 years, these predictions have a significant degree of uncertainty. Nevertheless, the results of this study are in agreement with previous research conducted in Europe.

Climate change is faster than forest tree species' adaptation and current scenarios show that in the context of global warming, with increasing temperatures and decreasing precipitations, forest tree species are likely to migrate north or to a higher altitude [28]. Therefore, we need to take into account the assisted migration of forest tree species, an intentional anthropogenic movement of individuals and populations. In this context, adapted populations need to be ex situ conserved and used for the production of seedlings. In this context, the narrow-crowned Norway spruce ideotype could be used by researchers and professional workers on forest restoration and afforestation activities, in the environmental conditions favorable for Norway spruce, with some of them described in the present study as well as in other previous research [7,35,37,52].

It would be profitable if future research directions reflected a desire to promote the narrow crown Norway spruce ideotype, for which a clonal seed orchard will be established, where a part of the last Romanian *pendula* spruce populations (which reached 120–160 years old) will be reproduced. Additionally, investigations will continue at the DNA level in order to determine how the character is transmitted. The environmental conditions in which this ideotype developed very well will be more closely investigated to try to determine the importance of the local environmental conditions.

5. Conclusions

The growth trait results from three comparative trials, belonging to different breeding levels (open-pollinated, half-sib, and full-sib, the last two being focused on the narrow crown Norway spruce ideotype, *pendula* form), were superior to the unimproved neighbor populations (26%–79% for volume/ha) and the differences increased if only the best 10% seed trees of the trials were used in the evaluation.

For Th, a five times higher family mean heritability was registered for the *pendula* trees in the half-sib trial, while in the full-sib experiment, the *pendula* trees (both full and half *pendula*) again registered higher heritability but for Dbh, which suggests the *pendula* selection for different traits in the two trials.

The profitability of using FRM from FGR ranged between 540 and 3366 €/ha, a value that is predicted to increase until the end of the rotation period (110 years), when the genetic gain could generate a profit of 7560 €/ha.

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