INFLUENCE OF SOIL TYPE ON MEAN TREE HEIGHTS OF FIR TREES IN A 40-YEAR PROVENANCE TRIAL

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Abstract
The study analyzed the heights of dominant fir trees from different regions. It was found that even when the trees were growing in the same type of soil, there were significant variations in their heights depending on their origin. Additionally, within the same region, the dominant heights of trees were significantly lower in the ranker compared to the district cambisol, except in the Olovo-Palež region.

Keywords: dominant tree height, provenance, soil characteristics.

INTRODUCTION
Over the past five decades, Serbia has undergone extensive reforestation initiatives, primarily focusing on conifer species to reclaim barren lands and rehabilitate degraded sites and stands. These reforestation efforts have predominantly involved Austrian pine, Scots pine, and spruce, with the notably limited participation of fir. Consequently, the growth characteristics of fir in artificially established stands, especially in stands established outside of the current fir habitats, are still insufficiently studied [1,2]. One of the primary objectives of provenance research is experimentally determining important hereditary traits, primarily growth patterns and tree vitality of a given species. This is particularly significant for fir, which exhibits a broad distribution across various habitats, giving rise to a wide variety of subspecies and ecotypes. By studying fir cultures in southwestern Serbia, where different fir provenances are planted side by side in the same site, a quantitative assessment of the success of their development was conducted.

MATERIALS AND METHODS
This study entailed a comparative analysis of dominant fir tree heights within artificially established stands, comprising nine provenances planted in the *Fagetum montanum* site of southwestern Serbia, specifically at the Reštevo site. The fir provenance trial was established at an elevation of 1,000 m, with a slope of 10° and a northwestern aspect. The trial was set up in a degraded beech stand that had undergone clear-cutting. Following the felling of beech trees, the stumps were treated with oyster mushroom mycelium to suppress their sprouting

ability. Fir seedlings were propagated from seeds sourced from diverse locations within the natural fir range [3]. The sowing took place in 1988. After they had been nurtured in the nursery for three years, the seedlings underwent a two-year training period (3+2), meaning that they were five years old at the time of planting in the trial. After the research conducted in the nursery, a field trial was established, comprising the following nine provenances: Prozor (PR), Bugojno (BU), Olovo-Klis (OK), Sokolac (SO), Olovo-Palež (OP), Pale (PA), Fojnica (FO), Konjic (KO), and Petrovac (BP). The trial was organized using a block system (two blocks, each containing nine replications). Fir seedlings were planted at a spacing of 2 m between seedlings, while the spacing between blocks with different provenances was 4 m. Within each block, 64 seedlings of the same provenance were planted in a single plot. Thorough soil investigations were conducted within each block. The results were analyzed using analysis of variance (ANOVA), and the post hoc procedure was conducted using the Bonferroni and Holm multiple comparison method. Data processing utilized the R programming language. Table 1 presents fundamental data regarding the stands from which the seeds were sourced to establish the trial.

Table 1 *Fir Provenances – Site Characteristics of Parent Stands*

Provenance	Soil	Site	Elevation (m)	Aspect	Slope (%)
Prozor (PR)	Calcomelanosol, Luvisol	*Piceo-Abietum Fagetum*	1.300	N-E	5–10
Bugojno (BU)	Calcocambisol	*Piceo-Abietum*	1.090	N-W	10–25
Olovo-Klis (OK)	Luvisol-calcocambisol	*Abieto-Picetum Illyricum*	850	N-W	13
Sokolac (SO)	Calcomelanosol	*Abietum Piceetum Syllicicolum*	940	S-W	13
Olovo-Palež (OP)	Calcocambisol, Luvisol	*Galio-Abietetum*	960	N-E	12
Pale (PA)	Dystric Cambisol, Calcomelanosol	*Abieto-Picetum Illyricum*	1.200	N-E	20
Fojnica (FO)	Dystric Cambisol	*Piceo-Abietuum Syllicicolum*	1.010	-	-
Konjic (KO)	Calcocambisol Calcomelanosol	*Abietum-Fagetum Illyricum*	1.030	E-NE	10–22
Petrovac (BP)	Calcocambisol, Pseudogley	*Abieto-Picetum Illyricum*	900	N	2

Source: [3].

RESULTS AND DISCUSSION

Soil characteristics

Table 2 displays the results regarding soil physical properties, while Table 3 outlines the chemical characteristics of the soil across different blocks.

Block A:

The terrain exhibits a slope of approximately 10° with a northwestern aspect. The depth of the topsoil layer exceeds 1m. Bedrock comprises sandstone, shale, and clay. The soil corresponds to a strongly acidic brown soil – dystric cambisol. Within the 0–32 cm depth, the humus-accumulative A horizon is dark brown with a black shade. Granulometric analysis reveals this horizon to be sandy clay loam containing 34.10% physical clay and approximately 15% coarse sand. The entire horizon is permeated with plant root systems and contains 30% skeletal material. The structure is well-defined with a crumbly to fine-grained texture. The soil is moist and humus-rich (4.29%), characterised by a mull-moder humus. Environmental pH is highly acidic, with active acidity at 4.8 pH units, potential acidity at 4.8 pH units, and hydrolytic acidity at 80.50 ccm. Base saturation is notably low, at 13.9%, with a base sum of 8.46% mil/eq. Assimilable phosphorus levels are high, while nitrogen and potassium are at moderate levels. The transition to the middle horizon is distinctly defined. This (B) horizon, found at a depth of 33–65 cm, is brown in colour with pronounced coarse redoximorphic mottles. Regarding its granulometry, the soil is notably heavier, characterised as sandy clay loam with 52.50% physical clay and 40% skeletal content. Humus content (1.33) and nutrient levels exhibit a sharp decline. Environmental pH is slightly less acidic. Beneath lies the C horizon, spanning from 65 to 100 cm. It is of the same colour but with a slightly lighter shade. The share of large skeletal fragments ranges up to 70%. The soil quality surpasses that of previously described trial fields, particularly in terms of the depth of the topsoil and granulometric composition, as the (B) horizon comprises more clay, contributing to better soil moisture retention. Chemical properties mirror those of prior trial fields, with the environmental pH even more acidic.

Table 2 *Physical properties of soil*

Block	Soil Type	Depth (cm)	Coarse Sand	Fine Sand	Silt	Clay	Total Sand	Total Clay	Texture Class
		cm	%	%	%	%	%	%	
A	Dystric Cambisol	0–32	15.00	50.90	22.70	11.40	65.90	34.10	Sandy Clay Loam
		32–65	14.00	33.50	24.80	27.70	47.50	52.50	Sandy Clay Loam
D	Ranker	0–36	7.50	65.10	18.50	8.90	72.60	27.40	Sandy Clay Loam

Table 3 *Chemical properties of soil*

Profile number	Depth cm	Adsorptive complex					pH		Total		Available		C/N
		T	S	T-S	V	Y1	H_2O	KCl	Humus	N	P_2O_5	K_2O	
		eq. m.mol NaOH			%	ccm			%	%	mg/100g		
A	0–32	60.81	8.46	52.35	13.91	80.50	4.8	3.7	4.29	0.16	20.0	9.5	15.5
	32–65	46.33	9.95	36.38	21.48	56.00	5.0	3.7	1.33		4.2	8.2	
D	0–36	37.76	8.48	29.27	22.46	45.00	5.3	4.2	4.56	0.20	20.0	7.0	13.2

Block D:

The terrain has a slope of 35° and faces northwest. Surface rocks are absent. The depth of the topsoil layer is approximately 50 cm. Bedrock includes sandstone, shale, and clay. The soil type is brown ranker. The A (humus-accumulative) horizon ranges from 0 to 36 cm and exhibits a dark brown colour. Granulometrically, it is composed of sandy clay loam, with 27.40% physical clay and 7.50% coarse sand. The horizon is permeated with skeletal material, constituting 40%. The fine soil displays a stable, crumbly structure. Root systems extend to a depth of 26 cm, with some individual roots reaching depths of 50 cm. Compared to Profile 1, the soil in Block D is notably drier. It is porous, permeable, and penetrable. The mature mull humus content (C/N – 13.22) measures at 4.56%, while the environmental pH registers as acidic at 5.3 pH units in water. The degree of base saturation is around 20%. The soil is well-supplied with nitrogen (0.20%) and phosphorus (exceeding 20 mg P_2O_5/100g of soil), though potassium levels barely reach the lower limit of moderate availability. The A-C/C horizon is 36–50 cm thick and exhibits a light brown coloration. This horizon has slightly higher moisture levels, with skeletal material constituting 90% of its volume, mixed with fine soil of similar physical and chemical properties. However, its productivity is constrained by a relatively shallow topsoil (approximately 5 cm) and the steep terrain, leading to intense erosion processes and significant forest damage caused by pruning.

Height of dominant trees

In natural stands, fir trees undergo a notably slow growth in their youth, while in artificially established stands, they grow significantly faster, nearly matching the growth rate of spruce, Scots pine, and Austrian pine. For instance, fir trees on Mount Goč within a natural stand regenerated through seed cutting reach a height of only three meters by the age of 30 [4]. In the majority of the utilized provenances, fir trees demonstrate relatively rapid height growth, indicating their vitality and successful development. Variations in height among them stem from their natural characteristics and the ability of provenance to adapt to new site conditions.

The average heights of dominant trees for the two analyzed blocks and provenances are presented in Table 4. After forty years of growth, notable differences were observed in the total dominant tree height attained by specific provenances (Table 5).

Table 4 *Basic statistical indicators of dominant heights by provenance*

Block	Height	Provenance								
		PR-1	BU-1	OK-1	SO-1	OP-1	PA-1	FO-1	KO-1	BP-1
Block A	Xmean	19.3	22.7	20.8	22.9	21.8	23.2	21.7	21.7	23.4
	Sd	1.8	1.0	1.9	1.7	1.6	2.1	1.4	1.1	1.0
	Kv%	9.3	4.3	9.3	7.4	7.2	9.2	6.5	5.3	4.2
Block D	Xmean	15.5	17.3	18.8	16.4	20.4	18.4	16.7	15.1	14.3
	Sd	0.9	2.1	1.3	1.0	2.1	1.2	1.2	2.4	1.9
	Kv%	6.0	11.9	7.1	6.1	10.1	6.3	7.4	16.1	13.3

Analysis of the provenance F-test showed significant differences between provenances within each analyzed block. The F-test value for Block A amounts to 6.02 (DF 9 and 72), whereas for Block D, it is 12.05 (DF 9 and 72).

In Block A, on dystric cambisol, significantly lowest dominant tree heights were observed in the Prozor (PR1) provenance (19.3 m), with notably lower values compared to the Bugojno (BU1), Sokolac (SO1), Olovo-Palež (OP1), Pale (PA1), and Petrovac (BP1) provenances. Additionally, significantly lower dominant heights were recorded for the Olovo-Klis (OK1) provenance compared to the Petrovac (BP1) provenance (Table 5).

On ranker soil, the Prozor (PR1) provenance in Block D exhibited significantly lowest dominant tree heights (19.3 m). These values were notably lower compared to the Olovo-Klis (OK4), Olovo-Palež (OP4), and Pale (PA4) provenances. Significantly lower values of dominant heights were observed for the Bugojno (BU4) provenance compared to the Olovo-Palež (OP4) and Petrovac (BP4) provenances. The Olovo-Klis (OK4) provenance demonstrated significantly higher dominant tree heights compared to the Konjic (KO4) and

Petrovac (BP4) provenances. The Sokolac (SO4) provenance displayed significantly lower heights of dominant trees than the Olovo-Palež (OP4) provenance. Moreover, the Olovo-Palež (OP4) provenance showed significantly higher growth of dominant trees compared to the Fojnica (FO4), Konjic (KO4), and Petrovac (BP4) provenances. Additionally, the Pale (PA4) provenance exhibited significantly greater heights of dominant trees compared to the Konjic (KO4) and Petrovac (BP4) provenances (Table 6).

Table 5 *Bonferroni and Holm multiple comparison method values between provenances in Block A*

Provenience	PR-1	BU-1	OK-1	SO-1	OP-1	PA-1	FO-1	KO-1	BP-1
PR-1	-								
BU-1	4.68**	-							
OK-1	2.01	2.64	-						
SO-1	4.86**	0.18	2.81	-					
OP-1	3.38**	1.30	1.33	1.48	-				
PA-1	5.35**	0.66	3.30	0.49	1.96	-			
FO-1	3.29	1.40	1.23	1.58	0.09	2.06	-		
KO-1	3.23	1.45	1.18	1.63	0.15	2.11	0.05	-	
BP-1	5.58**	0.89	3.53**	0.72	2.06	0.23	2.29	2.35	-

Table 6 *Bonferroni and Holm multiple comparison method values between provenances in Block D*

	PR-1	BU-1	OK-1	SO-1	OP-1	PA-1	FO-1	KO-1	BP-1
PR-1	-								
BU-1	2.30	-							
OK-1	4.12**	1.82	-						
SO-1	1.07	1.23	3.05	-					
OP-1	6.18**	3.88**	2.06	5.10**	-				
PA-1	3.68**	1.39	0.43	2.61	2.49	-			
FO-1	1.52	0.78	2.59	0.45	4.66**	2.16	-		
KO-1	0.56	2.87	4.68**	1.63	6.74**	4.25**	2.09	-	
BP-1	1.54	3.85**	5.67**	2.62	7.73**	5.23**	3.07	0.98	-

Through the application of Bonferroni and Holm t-statistic and conducting tests on the same provenances growing on different soil types, it was observed that provenances planted on dystric cambisol (Block A) exhibited significantly greater heights of dominant trees compared to those planted on ranker soil (Block D). The exception to this trend was the Olovo-Palež provenance, for which the difference was not statistically confirmed (Table 7).

Table 7 *Bonferroni and Holm multiple comparison method values of the same provenance between blocks*

Provenance	Bonferroni and Holm t-statistic	Bonferoni inference	Holm inference
PR1 vs PR2	5.61	<0.01	<0.01
BU1 vs BU2	7.08	<0.01	<0.01
OK1 vs OK2	2.59	<0.05	<0.05
SO1 vs SO2	9.93	<0.01	<0.01
OP1 vs OP2	1.63	insignificant	insignificant
PA1 vs PA2	5.92	<0.01	<0.01
FO1 vs FO2	7.96	<0.01	<0.01
KO1 vs KO2	7.32	<0.01	<0.01
BP1 vs BP2	12.62	<0.01	<0.01

CONCLUSIONS

Our research has revealed significant differences in the heights of dominant trees from different provenances. Testing these heights on different soil types showed that, for all provenances (except Olovo-Palež), heights were notably greater on dystric cambisol compared to ranker soil. This underscores the importance of soil type as a significant factor influencing the height of dominant fir trees. In forest management practices, it is crucial to recognise soil type as an indicator of site fertility for fir trees. Additionally, dominant heights play a pivotal role in determining Site Index or productivity classes, which should be carefully considered in future afforestation or reforestation initiatives aimed at rehabilitating degraded forests.

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REFERENCES

[1] Gagov V., Ergebnisse des 8. Tannen–Symposiums: Schriften aus der IUFRO und der Forsttechnischen Universität Sofia, Sofia, Bulgarien (1997) 89–108.

[2] Ratknic M., Vuckovic M., Stamenkovic V. *et al.*, Mitteilungen aus der Forschungsanstalt für Waldökologie und Forstwirtschaft, Rheinland – Pfalz. 50/3 (2002) 59–67.

[3] Ballian D., Halilović V., Varijabilnost obične jele (Abies alba Mill.) u Bosni i Hercegovini (Variability of the Silver Fir (Abies alba Mill.) in Bosnia and Herzegovina), Udruženje inženjera i tehničara Federacije Bosne i Hercegovine (UŠIT FBiH, Silva Slovenica – izdavački centar Šumarskog instituta Slovenije, Ljubljana (2016), p.350, ISBN: 978–9926–8071–0–8.

[4] Stamenković V., Vučković M., Ratknić M., Ergebnisse des 8. Tannen–Symposiums: Schriften aus der IUFRO und der Forsttechnischen Universität Sofia, Sofia, Bulgarien (1997) 185–192.