Analysis of Height and Diameter at Breast Height for Douglas fir Provenances Test

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Abstract. *Height and diameter breast height (DBH) were analysed for four provenances of Douglas fir (Cottage Grove, Centralia, Cascadia and Ashland) and differences among them were determined. The experiment was laid out as a Latin square 4x4 with 7x7 seedlings in each repetition. Repeated measures analysis of variance was conducted to analyse the differences in height and girth increments for individual provenances for 1970, 1980, 1990 and 2000. Research results indicated that there is a statistically significant difference in height and DBH for the studied years. There is also a significant difference in height among the provenances as well as an interaction of years x provenance. In the analysis of DBH, the difference among provenances was not statistically significant, nor was the interaction with years significant.*

Keywords. Douglas Fir Provenances Test, Repeated measures ANOVA, Height, Diameter breast height

1. Introduction

Planned and organized activities to increase the share of conifers in Croatia's forest fund began in 1960. In addition to the indigenous species of common spruce, common pine, black pine and Aleppo pine, four species of introduced conifers were used for establish new cultures: Douglas fir, European and Japanese larch, Eastern white pine and others [1]. Considering that there was little professional and scientific experience in Croatia concerning the establishment and breeding of forest cultures and plantations, systematic studies began after 1950 with permanent field experiments distributed throughout Croatia in various stands. As such, an experiment for the Douglas fir provenances was established in the region of the Kutina Forest Region at Mikleuška.

The objective of this study was to analyse the height and girth increments of individual Douglas fir provenances and to establish the adaptability and differences among the provenances.

2. Material and methods

The Douglas fir (*Pseudotsuga menziessi)* provenances experiment was established in 1966 using the Latin square design 4x4 (Fig. 1). The experiment included four provenances: 1. Cottage Grove-Oregon; 2. Centralia-Washington, 3. Cascadia-Oregon and 4. Ashland-Oregon. In each repetition, 49 seedlings (7x7) were planted, i.e. a total of 196 seedlings per provenance. Two-year seedlings were planted. Seedlings were grown in Jiffy-pots. The protective borders around the experiment were made up of two edge liners and one liner between blocks. Planting spacing was 2x2 m. The overall size of the experiment was 4624 m^2.

Compo nent	Vertical			
Horizontal	1	2	3	4
	2	4	1	3
	3	1	4	2
	4	3	2	1

Legend: 1 Cottage Grove
2 Centralia
3 Cascadia
4 Ashland

Figure 1. Experimental design.

Table 1. Descriptive statistics for height (m) and DBH (cm) for four analyzed provenances and years.

				Years			
	Provenance	Nb	Na	1970	1980	1990	2000
Height (m)	Cottage Grove	192	69	1.695±0.42	10.657±1.64	20.730±1.80	24.902±1.90
	Centralia	194	52	2.031±2.54	10.879±1.08	21.375±1.91	25.161±2.48
	Cascadia	192	82	1.730±0.40	11.046±1.27	21.095±2.35	25.475±2.59
	Aschland	162	66	1.681±0.37	10.347±1.25	20.489±1.77	24.213±2.44
DBH (cm)	Cottage Grove	110	56	1.041±0.62	13.866±2.17	23.093±4.69	28.536±7.48
	Centralia	94	46	1.204±1.62	14.330±2.48	23.500±4.90	28.641±8.97
	Cascadia	123	70	1.040±0.56	13.739±2.60	21.814±5.11	26.693±8.13
	Aschland	94	57	0.986±0.53	13.996±2.14	22.579±4.75	27.877±7.47

Note: Nb- Number of observation in main base; Na- number of observation without missing values.

In this study, we investigated height (m) and diameter at breast height (DBH in cm) for 1970, 1980, 1990 and 2000. Descriptive statistics (mean and standard deviation) were conducted for the analysed variables (height and DBH) by provenance for the observed years. Type I error (α) of 0.05 are considered statistically significant. The difference between DBH and height for the observed years was tested using the repeated measures Analysis of variance (ANOVA) test. Observations with missing values (i.e. without data for all four study years) were not included in this analysis. Only 269 observations could be used in the height analysis, and 229 for the DBH analysis.

Seedlings were analysed as a random effect, while all other effects were treated as fixed effects. Considering that the experiment was planned as a Latin square, we included the vertical and horizontal effects as a source of variability between subjects in addition to the provenance effects. In testing the within subjects effects, we included the years effect and all the double interactions between years and effects in between subject tests. The model of repeated measures ANOVA is shown in Table 2. It can be expected that the years effect will be substantial due to the large time interval (10 years), and we will perform subsequent testing for the effect of linear, quadratic and cubic trends for years. In the event there is a significant difference between the provenances, the Tukey-Kramer multiple comparisons post hoc test is used to determine which of the provenances is causing the difference for individual years [4].

All statistical analyses were conducted used the SAS 8.0 statistical package [2]. Graphs were produced using the STATISTIC 6.0 program [3].

Table 2. Results of Repeated Measures ANOVA

	Height				DBH			
Source of Variability	df	MS	F	p	df	MS	F	p
Between trees								
Provenances	3	31.60	4.25	**0.0059**	3	51.15	0.96	0.4141
Vertical component	3	13.48	1.81	0.1452	3	26.42	0.49	0.6867
Horizontal component	3	8.57	1.15	0.3285	3	62.47	1.17	0.3227
Error (between)	259	7.44			219	53.47		
Within trees								
Years	3	27572.89	15909.0	**<0.0001**	3	30116.92	2214.23	**<0.0001**
Years*Provenances	9	3.47	2.00	**0.0367**	9	10.98	0.81	0.6095
Years* Vertical comp.	9	2.47	1.42	0.1732	9	9.58	0.70	0.7052
Years*Horizontal comp.	9	1.88	1.08	0.3734	27	19.10	1.40	0.1824
Error (within)	777	20,4			657			

3. Results

Table 1 shows the descriptive statistics for the analysed variables (DBH and height) by provenance for the observed years. The results of the repeated measures ANOVA are provided in Table 2. It is evident that there are statistically significant differences in both height and DBH over the observed study years.

Contrast tests for linear, quadratic and cubic trends for Years for height are statistically significant (linear: F=21993.20, p<0.0001; quadratic: F=15194.90, p<0.0001; cubic: F=2188.57, <0.0001). The results are for DBH are similar: (linear: F=2427.57, p<0.0001; quadratic: F=968.66, p<0.0001; cubic: F=381.88, <0.0001).

There is a statistically significant difference in height among the provenances (Table 2). The interaction of years x provenance also showed statistically significant differences, which indicates that the provenances did not grow uniformly over time. Tukey's post hoc test confirmed this. Tukey's test showed that heights in 1970 were not statistically difference. In 1980, statistically significant differences were noted between the Cascadia and Ashland provenances (p=0.0042). In 1990, there was no statistically significant difference in height, while in 2000, the difference between Cascadia and Ashland is again statistically significant (p=0.005).

No statistically significant differences were found for DBH among provenances.

Figure 3. Mean and 95% confidence intervals for height (m) for four provenances per studied years.

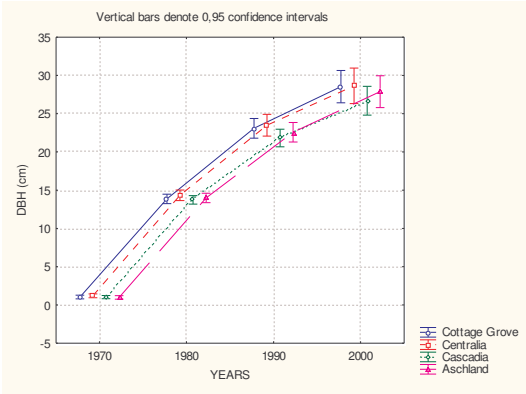

Figure 4. Mean and 95% confidence intervals for DBH (cm) for four provenances per studied years.

4. Discussion

The results of the height study indicate that there is a statistically significant difference in height and DBH through the observed years, which is the expected results consider the 40 year study period. The statistically significant interaction in height among the provenances and years indicates that the provenances did not develop uniformly over time. In 1970, the differences were not significant, while in 1980, Cascadia showed a statistically significant difference only with the Ashland provenance, which showed the lowest mean growth over all 4 study years. In 1990, the height differences were not statistically significant, which suggests a gradually equalization in height, while in 2000 the difference between Cascadia and Ashland was again significant.

One of the reasons for such a result could be the genetic heterogeneity of the provenances. A second reason could be abiotic factors. Namely, temperature and the water regime in those years perhaps did not suit the individual provenances (i.e., Ashland). All results obtained indicated the intensive growth in height of Douglas fir in beech habitats in Croatia. The DBH results did not indicate statistically significant differences among the provenances, which suggests relatively uniform girth increments for all four provenances. The possible ambiguities concerning the disproportionate results among provenances for height and DBH could be due to the fact that in the first 40 years, the growth in height is far more emphasized in Douglas fir than girth, and that an increase in girth is expected in the coming years. Namely, these

trees primarily achieve the culmination of their growth in height, and only later achieve an increase in girth.

5. Acknowledgements

We would like to thank the Ministry of Science, Education and Sports of the Republic of Croatia for their support of the research reported in this paper in project numbers 0024002 and 0068138.

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