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TESTING OF AMERICAN, GERMAN AND BULGARIAN DOUGLAS-FIR PROVENANCES ON TWO TEST SITES IN BULGARIA SIX YEARS AFTER OUTPLANTING

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Abstract

Two provenance tests with 29 German, American and Bulgarian Douglas-fir provenances were established in Bulgaria with 2-year-old plants in 2006. The trials were established in the forest enterprises “Berkovitsa” (Western Balkan Range) and “Borima” (Central Balkan Range). The spacing was 2 x 2 m, with 49 and 25 plants per plot, respectively, with three replications. The trials were evaluated for survival, mean growth and current annual height increment in the last (the sixth) year after outplanting. The results show that the trees in “Berkovitsa”, which grow on more suitable site according to climate, had less mortality and better growth compared to these on the site “Borima”. Statistical analysis shows the beginning of differentiation between the provenances. Differences between the provenance regions are insignificant. Indications are given for the procurement of Douglas-fir seed for Bulgaria.

Key words: current height increment, Douglas-fir, height growth, provenance trials, survival.

Introduction

Douglas-fir is one of the most frequently introduced coniferous tree species in Europe. One of the main prerequisites for profitable management of Douglas-fir plantations is their high productivity. Numerous provenance tests were carried out in Europe to establish the most appropriate and most productive origins (Hermann and Lavender 1999, Govedar et al. 2003, Zas et al. 2004, Isajev and Lavadinović 2007, Weller 2012, Bastien et al. 2013, Lavender and Hermann, 2014). In one of the first provenance tests, carried out in 1910, 10 provenances of the three varieties (subspecies) of Douglas-fir were introduced, namely var. *viridis* (“green” coastal Douglas-fir), var. *caesia* (“gray” Douglas-fir) and var. *glauca* (“blue”

Douglas-fir). The results of 90 years of research confirmed the better growth of green Douglas-fir (var. *viridis*) compared to the other two varieties (Stimm and Dong 2001).

During the period 1923–1930 the first Douglas-fir provenance tests were carried out in the Netherlands. Studies on growth in height and volume also show the better opportunities of coastal versus continental provenances (Veen 1951).

In 1969 a Douglas-fir provenance test (Perić et al. 2009) was made in Istria (Croatia). The experiment covered 10 provenances – seven from the United States (five from Washington and two from Oregon) and three from Denmark, Bulgaria and Croatia. The average survival rate at the age of 40 of all provenances amounted to 64.8 %. The best growth in height was found in the SHELTON provenance from Washington, and the lowest – in SHADE COVE from higher altitude in Oregon. All provenances were vital and in good health condition. In 1982 the Institute of Forestry in Belgrade carried out two provenance tests in Central and Eastern Serbia with 18 Northamerican provenances from Oregon to British Columbia (Lavadinović et al. 2009). Growth in height in the 15-th year of age varied from 43 to 89 cm with an average of 75.2 cm.

In 1987, seeds from 55 American Douglas-fir provenances (6 from the coast of Washington and Oregon, 8 continental, 38 from the Cascade Mountains and 3 from the states Arizona, Montana and New Mexico) were imported in Bulgaria. They were used for germination tests and early diagnosis of seedlings in nursery (Popov 1990, Petkova and Popov 1998). Several provenance tests were established in Bulgaria with seedlings from these provenances. The coastal provenances and these from Cascade Mountains from the states of Washington and Oregon are characterized with the best growth. The continental provenances lag behind in growth and show a strong sensitivity to fungal pathogens *Rhabdocline pseudotsugae* Syd. and *Phaeocryptopus gaeumanii* (T. Rohde) (Popov 1995, Popov 2001, Petkova 2011).

To provide high quality seeds of Douglas-fir, particularly in forecasted climate change, two provenance tests with seeds from German, Bulgarian and American stands were established in 2006. The first results of this experiment have been published (Petkova et al. 2008).

The purpose of this work was to present the results of studies on the survival rate and height growth of Douglas-fir of the sixth year after the planting.

Objects and Methods

Objects of this study were two Douglas-fir provenance tests, established in the spring of 2006 in Forest Enterprises Berkovitsa (Western Balkan Range) and Borima (Central Balkan Range). The experiment covers 29 provenances (Table 1), of which 20 from older stands in Germany (8 from Bavaria, 7 from Rhineland Palatinate and 5 from Lower Saxony), 6 from selected Douglas-fir stands in Washington (USA) and 3 from older Douglas-fir plantations in Bulgaria.

The provenance tests were established in a 2×2 m plot design in three replications, in Berkovitsa with 49 (7×7 m) plants on each plot, in Borima – 25 (5×5 m) plants on each plot.

The trial in Berkovitsa was established at the top of the northeast facing

Table 1. Data for Douglas-fir provenances included in the provenance tests.

No	Country or province	Provenance region, code	Register, No	Forest enterprises	Altitude, m	Geographic coordinates	
						Longitude	Latitude
1	Bavaria	853 04	91853041851	Münnerstadt	300–310	10°12’	50°13’
2	Bavaria	853 04	91853040941	Lohr	440–455	9°30’	50°0’
3	Bavaria	853 04	91853041161	Schweinfurt	380	12°14’	50°3’
4	Bavaria	853 06	91853060171	Stadtsteinach	490–600	11°34’	50°13’
5	Bavaria	853 06	91853060381	Schnaittenbach	480–500	11°58’	49°30’
6	Bavaria	853 05	9185304222	Griesbach	460–510	13°13’	48°27’
7	Bavaria	853 05	9185304043	Freising	420	11°45’	48°24’
8	Bavaria	853 06	91853060211	Stadtsteinach	550–650	11°31’	50°10’
9	USA	422-2.0	EC-20 (1995)	Mineral, Wa	533	122°10’	46°42’
10	USA	403-1.5	EC-13 (1998)	Darrington, Wa	381	121°35’	48°22’
11	USA	403-1.0-1.5	EC-11 (2001)	Darrington, Wa	381	121°45’	48°20’
12	USA	403-1.0-1.5	EC-41 (2001)	Darrington, Wa	381	121°33’	48°20’
13	USA	403-1.0-1.5	EC-13 (2001)	Darrington, Wa	381	121°35’	48°22’
14	USA	012-3.0	no data	Forks, Wa	838	124°13’	48°05’
15	Rhineland Palatinate	853 04	72853040014	Kaiserslautern	280–310	7°46’	49°25’
16	Rhineland Palatinate	853 05	73853050162	Osburg	565–590	6°45’	49°45’
17	Rhineland Palatinate	853 04	71853040432	Mayen	410–500	7°00’	50°17’
18	Rhineland Palatinate	853 05	73853050232	Daun	560–620	6°41’	50°10’
19	Rhineland Palatinate	853 05	73853050182	Schneifel	530	6°30’	50°15’
20	Rhineland Palatinate	853 05	73853050102	Gerolstein	520–550	6°30’	50°15’
21	Rhineland Palatinate	853 04	72853040013	Kaiserslautern W	280–310	7°46’	49°25’
22	Lower Saxony	853 01	31853040012	Oldendorf	180	9°27’	51°56’
23	Lower Saxony	853 04	34853040013	Münden	300	9°46’	51°19’
24	Lower Saxony	853 01	31853040013	Oldendorf (SPl)	290	9°25’	51°51’
25	Lower Saxony	853 01	35853010212	Ahlhorn	30	7°58’	52°54’
26	Lower Saxony	853 01	11853010091	Segeberg	40	10°07’	53°56’
27	Bulgaria	PME135	no data	Smiljan	950	24°46’	41°38’
28	Bulgaria	PME095	C02PME09500132	Kazanlak	750	25°26’	42°38’
29	Bulgaria	PME064	no data	Newestino	650	22°46’	42°12’

slope with gradient 8 ° and altitude a.s.l. 850 m, latitude 43°13'9.78'' N and longitude 23°05'25.02'' E. The soil is Cambisols (FAO), mixed sandy and clay, slightly stony, friable, deep, fresh to moist, on subsoils schists. The habitat is medium rich to rich. The reaction of the soil is acidic (pH = 4.67). The climate in the region is temperate with average annual temperature 10.4 °C and average temperature in the growing period (April–September) 17.4 °C. The absolute maximum temperature reaches up to 40.6 °C, and the absolute minimum temperature drops to –23.2 °C. The average annual precipitation amount is 825 mm. More than half of the rainfall (488 mm) comes during the growing period (April–September).

The provenance test in Borima was located on the sunny south-facing slope with 14 ° and altitude 1067 m a.s.l., latitude 42°54'52.2'' N and longitude 24°53'41.2'' E. The soil is Cambisols (FAO), mixed sandy and clay, slightly stony, densified, medium deep, fresh to moist. The habitat is medium rich to rich. The climate is temperate, but more continental compared to Berkovitsa. The average annual temperature is 9.8 °C and the average temperature during the growing period (April–September) is 17.7 °C. The absolute maximum temperature reaches 39.8 °C, and the absolute minimum temperature drops to –28.2 °C. The average annual precipitation amount is 767 mm. More than half of the rainfall (446 mm) comes during the growing period (April–September).

In a trial in Forest Enterprise Berkovitsa the height and current annual height increment of 20 plants for each provenance and each replication were measured of the last (the sixth) year after planting 20 plants for each provenance and each replication. The values of average height and average survival rate were processed statistically with program Statistika 8.0. The Duncan multiple range test was used to establish the influence of the provenance on the mean height and current height increment, and the statistical significance of differences.

The height and last height increment of all trees were measured only for 12 provenances of the first replication at trial plantation in Borima. Because of large losses in the majority of provenances in that plantation there was not sufficient number of surviving trees. Data have not been processed statistically.

Results and Discussion

During the sixth year after the planting the survival rate of Douglas-fir in Berkovitsa is very high – an average of 94.4 % (Fig. 1).

The highest survival rate – 98.6 % was observed in provenances 25 Ahlhorn (Lower Saxony), 8 Stadtsteinach (Bavaria) and 13 Darrington (USA). With a very good survival of 98 % are characterized provenances 16 Osburg and 17 Mayen from Rhineland Palatine, 26 Segeberg from Lower Saxony and American provenance 11 Darrington, Wa. Survival below 90 % was demonstrated by American provenance 12 Darrington and two Bavarian provenances, 5 Schnaittenbach and 2 Lohr. Provenance 25 Ahlhorn was characterized with the fewest losses and provenances 2 Lohr (Bavaria) and 12 Darrington (USA) – with the most losses also of the first year after the planting (Petkova et al. 2008).

The data about the single groups showed (Table 2), that the highest survival rate in the test site in Berkovitsa had a group of Rhineland Palatinate – 96.4 %, followed by the group of Lower Saxony –

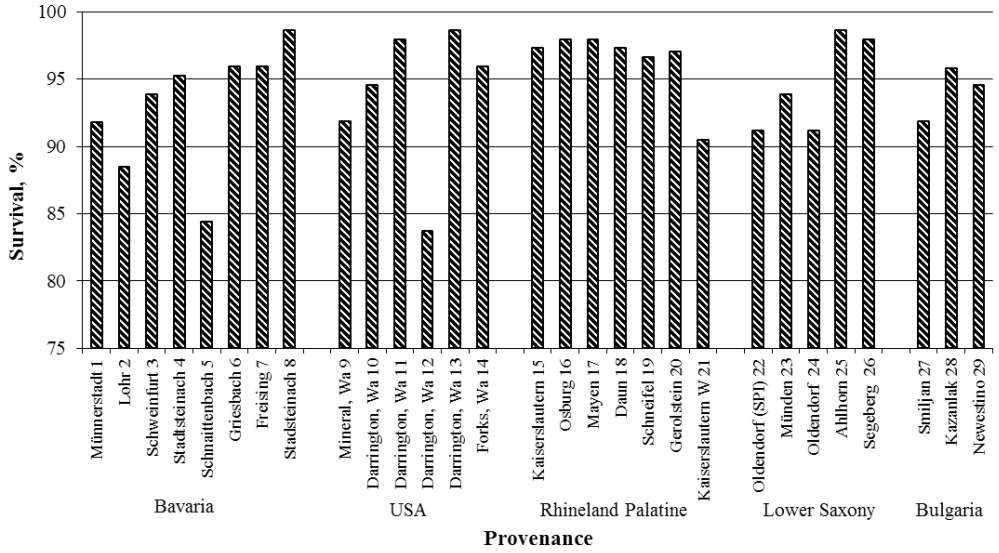

Fig. 1. Survival of Douglas-fir provenances on the test site Berkovitsa.

94.6 %. The Bavarian group had the lowest survival – 93.1 %. Average position was occupied by Bulgarian (94.1 %) and USA (93.8 %) groups. Overall losses in the test site in Berkovitsa were negligible.

The mean height of Douglas-fir in Berkovitsa in the sixth year after planting was 3.4 m. The differences between the provenances were minimal (Table 2).

One way analysis of variances (ANOVA) was used to establish the influence of the provenance, replication and interaction between them on the mean height of Douglas-fir in the test site in Berkovitsa by significance level of $p < 0.01$ (Table 3).

The results of the Duncan test (Table 4) showed that the mean height of provenances could be arranged in 13 homogeneous groups. Provenance 3 Schweinfurt (Bavaria) was characterized with the most

Table 2. Survival, mean height and current annual height increment of the last year after the planting of the provenance regions on the two test sites.

Provenance group	Survival, %		Height (H), m		Height increment (Zh), cm	
	Berkovitsa	Borima	Berkovitsa	Borima	Berkovitsa	Borima
Bavaria	93.1	64.0	3.5	2.6	94.4	86.7
USA	93.8	40.0	3.4	1.9	96.9	78.5
Rhineland Palatine	96.4	52.0	3.3	2.0	89.7	70.2
Lower Saxony	94.6	36.0	3.5	2.6	95.6	82.2
Bulgaria	94.1	64.0	3.3	2.4	86.1	77.8

Table 3. Significance of factors on the mean height in the provenance test in Berkovitsa.

Indicator	Degree of freedom	Mean square	Fisher's criterion	Significance level
Provenance	24	6.295	11.551	0.000
Replication	2	10.270	18.852	0.000
Provenance * Replication	48	3.224	5.916	0.000

rapid growth and had a mean height of 3.9 m, followed by provenances 23 Münden (Lower Saxony), 18 Daun (Rhineland Palatinate) and 11 Darrington (USA) with a height of 3.8 m, 26 Segeberg (Lower Saxony), 1 Münnerstadt and 4 Stadtsteinach (Bavaria) with a mean height of about 3.7 m. Provenance 18 Daun from Rhineland Palatinate showed rapid growth in height also in the first year after the planting (Petkova et al. 2008). Provenance Darrington was characterized by very good growth in 14 provenance trials and was recommended for planting in North-Western Germany (Weller 2010).

Provenance 19 Schneifel (Rhineland Palatinate) was characterized as the slowest growing with a mean height of 2.6 m, followed by provenance 24 Oldendorf (Lower Saxony) and 5 Schnaittenbach (Bavaria) with a mean height of about 2.8 m. Genetic studies have shown that provenance 5 Schnaittenbach belongs to the subspecies gray Douglas-fir (Konnert and Ruetz 2006, Konnert et al. 2010, Konnert and Fussi 2012). Other provenances showed an average growth in height.

A comparison of the mean height of 12 provenances of the experimental trial in Borima with the same in Berkovitsa showed that these in Borima had less growth (Table 4). An exception was the provenance 6 Griesbach, which in both areas had similar mean height. This provenance could be described as highly adaptive to different conditions of the habitat.

The current annual height increment of the last (the sixth) year after the planting in Berkovitsa was 93.3 cm. The best height increment was found in American provenances – 96.9 cm, and the lowest – in Bulgarian ones – 86.1 cm (Table 2). The Bulgarian provenances showed the poorest height increment also in the first year after the planting (Petkova et al. 2008).

The performed one way analysis of variances (ANOVA) showed the importance of the provenance, replication and combination of provenance and replication on the height increment of Douglas-fir experimental trial Berkovitsa at significance level $p < 0.01$ (Table 5).

The results of the Duncan test showed that height increments of all provenances were arranged in 10 homogeneous groups (Table 6). The largest height increment was measured in provenance 11 Darrington (USA) – 106.9 cm, followed by provenances Münden 23 and 26 Segeberg (Lower Saxony), 3 Schweinfurt (Bavaria), 22 Oldendorf (SPI) from Lower Saxony, 12 and 10 Darrington (USA) and 6 Griesbach (Bavaria), which also have a considerable current height increment from 101.1 to 104.7 cm.

With the poorest height increment were characterized provenances 5 Schnaittenbach (Bavaria), 19 Schneifel (Rhineland Palatinate) and 24 Oldendorf (Lower Saxony). These provenances also had the lowest height. Provenance 5 (Schnaittenbach) had the poorest height increment also in the first year after planting (Petkova et al. 2008). The

Table 4. Mean heights (H) of the Douglas-fir provenances six years after planting and Duncan multiple range test results for provenances in Berkovitsa.

Provenance	Borima	Berkovitsa												
	H±S.E., m	H±S.E., m	Homogeneous groups											
Schneifel 19	1.85±0.25	2.62±0.11	a											
Oldendorf 24		2.76±0.11	a	b										
Schnaittenbach 5		2.83±0.12	a	b	c									
Mineral, Wa 9		3.05±0.11		b	c	d								
Lohr 2		3.06±0.09		b	c	d	e							
Smiljan 27		3.11±0.12			c	d	e							
Mayen 17	1.52±0.15	3.18±0.11				d	e	f						
Forks, Wa 14		3.23±0.08				d	e	f	g					
Kaiserslautern W 21		3.35±0.09				d	e	f	g	h				
Gerolstein 20	1.66±0.10	3.36±0.11				d	e	f	g	h	i			
Newestino 29		3.39±0.13					e	f	g	h	i			
Osburg 16	2.54±0.26	3.45±0.12						f	g	h	i	j		
Kazanlak 28	2.38±0.19	3.46±0.11						f	g	h	i	j		
Kaiserslautern 15		3.47±0.10						f	g	h	i	j	k	
Darrington, Wa 13		3.48±0.10						f	g	h	i	j	k	l
Ahlhorn 25	2.63±0.20	3.49±0.10						f	g	h	i	j	k	l
Darrington, Wa 10		3.49±0.10						f	g	h	i	j	k	l
Oldendorf (SPI) 22		3.54±0.10							g	h	i	j	k	l
Griesbach 6	3.17±0.13	3.55±0.09							g	h	i	j	k	l
Stadsteinach 8		3.55±0.10							g	h	i	j	k	l
Darrington, Wa 12		3.58±0.10								h	i	j	k	l	m
Freising 7	2.06±0.22	3.63±0.10								h	i	j	k	l	m
Stadtsteinach 4		3.67±0.10								h	i	j	k	l	m
Münnerstadt 1	2.27±0.24	3.68±0.08								h	i	j	k	l	m
Segeberg 26		3.71±0.07									i	j	k	l	m
Darrington, Wa 11	1.93±0.14	3.78±0.11										j	k	l	m
Daun 18	2.52±0.21	3.81±0.10											k	l	m
Münden 23		3.82±0.10												l	m
Schweinfurt 3	2.72±0.22	3.90±0.09													m

Note: S.E. – standard error; different letters unit homogenous groups of provenances without significant difference between mean height by tested provenances according to Duncan's multiple range test at the 0.05 significant level.

Table 5. Significance of factors on current annual height increment.

Indicator	Degree of freedom	Mean square	Fisher's criterion	Significance level
Provenance	24	4149.593	6.910	0.000
Replication	2	3973.095	6.616	0.001
Provenance * Replication	48	3431.374	5.714	0.000

Table 6. Current height increment of the Douglas-fir provenances of the last (the sixth) year after the planting (Zh) and Duncan multiple range test results for provenances in Berkovitsa.

Provenance	Borima	Berkovitsa										
	Zh±S.E., cm	Zh±S.E., cm	Homogeneous groups									
Schnaittenbach 5		76.0±4.9	a									
Schneifel 19	62.0±10.2	76.4±3.7	a									
Oldendorf 24		77.2±3.0	a									
Smiljan 27		82.8±3.8	a	b								
Mayen 17	48.4±7.4	85.4±2.9	a	b	c							
Mineral, Wa 9		86.1±3.6	a	b	c							
Lohr 2		86.7±4.1	a	b	c	d						
Newestino 29		88.1±4.3		b	c	d	e					
Kazanlak 28	77.8±6.4	88.3±3.8		b	c	d	e					
Gerolstein 20	60.8±4.3	88.5±3.1		b	c	d	e					
Osburg 16	91.5±8.9	89.7±3.8		b	c	d	e					
Ahlhorn 25	82.2±8.3	91.0±2.8		b	c	d	e	f				
Forks, Wa 14		91.7±2.9		b	c	d	e	f	g			
Stadtsteinach 4		92.4±2.9		b	c	d	e	f	g	h		
Kaiserslautern W 21		94.2±2.9			c	d	e	f	g	h	i	
Kaiserslautern 15		95.1±3.4			c	d	e	f	g	h	i	
Stadsteinach 8		95.9±2.9			c	d	e	f	g	h	i	j
Münnerstadt 1	75.0±8.8	97.7±4.1				d	e	f	g	h	i	j
Daun 18	88.5±7.9	97.9±2.9				d	e	f	g	h	i	j
Darrington, Wa 13		98.7±3.2					e	f	g	h	i	j
Freising 7	68.0±6.2	99.2±3.4					e	f	g	h	i	j
Griesbach 6	105.2±3.4	101.1±3.3						f	g	h	i	j
Darrington, Wa 10		101.8±3.3						f	g	h	i	j
Darrington, Wa 12		101.8±2.5						f	g	h	i	j
Oldendorf (SPI) 22		102.9±3.4							g	h	i	j
Schweinfurt 3	98.8±10.4	103.0±3.2							g	h	i	j
Segeberg 26		103.4±2.4								h	i	j
Münden 23		104.7±2.5									i	j
Darrington, Wa 11	78.5±7.7	106.9±2.9										j

Note: S.E. – standard error; different letters unit homogenous groups of provenances without significant difference between total height by tested provenances according to Duncan's multiple range test at the 0.05 significant level.

other provenances occupied a middle position.

The average height increment of the 12 surviving provenances in the test site in Borima was 78.1 cm. This value was significantly lower than that of the same provenances in Berkovitsa. Impressively high height increment was observed in provenance 6 Griesbach (Bavaria). The provenances 16 Osburg (Rhineland Palatinate), 3 Schweinfurt (Bavaria) and 18 Daun (Rhineland Palatinate) also showed very good height increment.

The high survival of Douglas-fir in Berkovitsa (94.4 %) was a sign of the very good conditions in this experimental trial. In some plants yellowing of the needles was observed, which could be explained by aggravated deteriorating microenvironment (waterlogging). Early formation of cones were found by some individuals, which indicates a weakening of the physiological condition.

In some plants, damages by game were observed – bites on the upper parts of the shoot, broken shoots and debarking. Affected plants were located most often near the bordering of the trial plantations.

Conclusions

The provenances from Germany and from the State of Washington (USA) had negligible losses and good growth at afforestation in Bulgaria.

Seeds from the stands of “gray” Douglas-fir, as well as seeds from the stand Schnaittenbach (Bavaria) should not be used. Whether this is the case with the stands of Oldendorf (Lower Saxony) and Schneifel (Rhineland Palatinate), should be checked genetically, because these provenances have a poor growth.

The great adaptability of Douglas-fir in different habitats, and its successful moving with 10° latitude on south of the original location were confirmed with negligible losses and good growth of the provenance test “Berkovitsa”. The larger losses and poor growth of the provenance test “Borima” are primarily due to inadequate care and lack of fence.

In the future, also in the context of climate change, the provenances of “green” Douglas-fir from the USA, as well as the genetically tested German stands, will be the only suitable ones. For the conditions in Bulgaria, regardless of somewhat poorer growth, they could rely on the seeds from older plantations in the country.

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