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Production potential of Douglas fir at mesotrophic sites of Křtiny Training Forest Enterprise

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ABSTRACT: The study evaluates production parameters (height, diameter at breast height, volume) of Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) at mesotrophic sites of the Křtiny Training Forest Enterprise in mature stands. In total, 29 mixed stands were assessed with the registered proportion of Douglas fir at an age of 85 to 136 years. Comparing the 10 largest Douglas firs with the 10 largest spruces or larches higher, and as a rule markedly higher, production potential of introduced Douglas fir was found in all assessed stands. There were also groups of trees where the volume of Douglas fir was twice to 3 times higher than the volume of spruce or larch (see Tabs. 5 to 10). For example, in stand 177B11, the mean volume of 9.12 m^3 was recorded in the 10 largest Douglas fir trees but the volume of spruce reached only 3.17 m^3 and the volume of larch was 3.70 m^3. Differences in mensurational parameters of Douglas fir found on the one hand and of Norway spruce (*Picea abies* [L.] Karst.) or European larch (*Larix decidua* Mill.) on the other hand compared by ANOVA tests were statistically highly significant. Annual ring analyses have shown that at present the volume increment of particular Douglas fir trees ranges from 0.12 to 0.16 m^3 per year in mature stands (i.e. about 1.5 m^3 every 10 years).

Keywords: Douglas fir; Norway spruce; European larch; production potential; mesotrophic sites

In 2005, within research programs of Ministry of Agriculture of the Czech Republic, the competition of tenders was announced, among others, in the thematic field *Using allochthonous species in multifunctional and sustainable forest management*. The author of the paper presented in the competition the draft of a project entitled *Douglas fir – the most important introduced species in multifunctional and sustainable forest management*. The project was accepted to be carried out in 2006–2009. It is dealt with at two forest estates. Primarily, research studies are carried out in forest stands of the Training Forest Enterprise (TFE) called Masaryk Forest at Křtiny. Douglas fir has been grown there since the 80s of the 19th century. At present, it occurs in all age classes at a proportion of 1.3% in the species composition (131 ha reduced area). It refers mainly to mesotrophic sites of management groups of stands 25 and 45.

The second series of research plots was established in Hůrky Training Forest District of the Secondary Forestry School in Písek. Unlike the Křtiny TFE, poor and acid sites, which are included in management groups of stands 23 and 43, predominate there. Also the growing of Douglas fir has more than one hundred year tradition there and at present, the species is recorded on more than 12% of the stand land (79 ha reduced area). The project is of the basic and applied research type being concentrated on these problems:

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– production potential and stability of Douglas fir as compared with the main indigenous conifers,
– possibilities of the natural regeneration of Douglas fir,
– the study of Douglas fir transpiration by direct measurements of transpiration flow,
– analysis of the accumulation and chemical composition of humus in stands with Douglas fir,
– analysis of the content of nutrients in assimilatory tissues of Douglas fir.

All these studies are carried out simultaneously in Křtiny TFE and Hůrky Training Forest District. The project output will consist of the comparison and objective assessment of growing this introduced species at acid and mesotrophic sites of uplands in this country. The presented study is the first published paper concerning the project. As already evident from the paper title its content and purpose are to assess the production potential of Douglas fir at mesotrophic sites of uplands (the 2nd or the 3rd forest vegetation zone). In assessing production capacities of introduced species it is necessary to mention at the first place data on their growth and production at the original habitat. Data on their production potential, i.e. maximum height, diameter and volume, are of great importance.

For example, Fowells (1965) mentioned a tree that reached dbh (diameter at breast height) 525 cm and height 72 m as the largest Douglas fir tree in the USA found until 1962. In addition to this, Šika and Vinš (1980) described the largest Douglas fir tree growing in the state of Washington ever measured and reaching a height of 117 m. The breast-height diameter of this tree was 457 cm. These authors reported on a Douglas fir tree of dbh 486 cm growing also in the state of Washington. A stand in the Olympic park (Washington) is considered to be one of the largest groupings of big Douglas fir trees. Douglas fir trees of the place aged 400–500 years reach a height of 90–100 m and dbh 2–3 m. It is also interesting that this stand occurs in the rain shadow of the Olympic mountain range, and mean annual precipitation amounts there only for 381 to 445 mm (Šika, Vinš 1980). The production potential of particular species is evident from yield tables. For Douglas fir from the region of W. Washington and Oregon, Šika and Vinš (1980) referred to tables compiled by McArdl in 1930. According to these tables, Douglas fir is divided into five site classes. The first class is characterized by height 61 m and growing stock 1,340 m^3/ha at 100 years, the second class by height 52 m and growing stock 1,160 m^3/ha. In the 60s of the 20th century, Hofman (1964) compared in detail the growth and production of North American Douglas fir with Douglas fir growing in Europe. The author concluded that the height growth of the species in Europe did not reach such parameters as in America.

A number of interesting findings on the production potential of Douglas fir in Central Europe can be found in German studies. For example, Huss (1996) reported that the oldest Douglas fir trees in forests of the town of Freiburg reached a height of 55 m being even at this age considerably vital. Based on this fact he concluded that similarly like in North America, Douglas fir could reach a height of 70–80 m at sufficient rotation. In 80-years old stands, the annual increment of Douglas fir amounted to 15 m^3/ha, and thus it exceeded all other indigenous species more than twice.

In the same area, Burgbacher and Greve (1996) analyzed the results of their investigations in a stand of rich species composition (Douglas fir, silver fir, beech, larch, spruce, oak). The monitored area of 0.3 ha dominated by Douglas fir showed a growing stock of 574 m^3/ha and mean height 31.4 m at the age of 52 years. At the age of 75 years, the mean height of Douglas fir amounted to 40.6 m and growing stock to 820 m^3/ha and, finally, at the age of 85 years, Douglas fir reached the mean height of 45.4 m and growing stock of 891 m^3/ha.

Kenk and Ehring (1995) reported even higher parameters of Douglas fir stands growing in the region of Black Forest where mean temperatures reached 7.2°C and annual precipitation about 1,300 mm. The stand established in 1891 had been monitored since 1949, when it reached a growing stock of 703 m^3/ha at the mean height of 37 m. At the age of 100 years, i.e. in 1991, its mean height amounted for 50 m and growing stock reached 1,387 m^3/ha. This growing stock exceeded definitely the growing stock of a spruce/fir stand of the same age (722 m^3/ha), the current volume increment being 1.5 times higher at the last measurement in the Douglas fir stand (25 m^3/ha/year).

Also under conditions of the Czech Republic, findings on the position, growth and production of Douglas fir are continuously presented in forest scientific and technical papers. It is of interest that a number of MSc and PhD theses of students of faculties of forestry in Prague and Brno deals with Douglas fir problems. With respect to the subject of this study only those papers are commented in the following text that evaluate the species at mesotrophic sites.

Wolf (1998) described the history and particularly the present condition of a 113-years-old Douglas fir stand in the group of forest types 4B in forests of

the town of Písek. Total annual precipitation in the studied area ranges between 650 and 700 mm. On the basis of mensurational data from 1997, the author found that out of the total number of 139 trees in the stand, 50 trees were higher than 45 m and 15 trees showed a volume exceeding 10 m^3. dbh of the largest trees reached 95–98 cm. The volume of the mean stem for the upper storey of the stand was determined to be 6.4 m^3 at the mean dbh 69.0 cm. The upper storey growing stock reached 661 m^3/ha at stand density 0.6–0.7 in 1997. In the technical note of Blaščák (2003), a considerable production potential of Douglas fir at mesotrophic sites of uplands was also proved. Nevertheless, the author referred to potential risks of its growing at these sites at wind disasters. On the other hand, Dolejský (2000) regarded the species as not only exceptionally productive but also resistant to the effect of icing and destructive winds. The author stated that Douglas fir resisted to these abiotic factors much better than any other indigenous coniferous species and thus could be compared with broadleaves. The Douglas fir production was on average 30% higher (for a stand aged 100 years) than the production of spruce.

Problems of the Douglas fir growth were studied in detail in the area of the Czech Republic (CR) by Šika and Vinš (1980) in the 70s of the last century. They started from the evaluation of a series of 76 research plots established in Douglas fir stands aged over 50 years. The aim of their study was to evaluate the growth of Douglas fir under various site conditions throughout the area of the CR and subsequently to carry out comparisons with spruce. The mean stand heights of Douglas fir in their experimental plots ranged from 30 to 45 m for the stand age of 85 to 95 years. The greatest height (51 m) was reached by a tree in a stand aged 93 years at the site of moist fir-beech forests. The values of mean dbh in stands aged about 90 years ranged from 43 to 54 cm.

It is also interesting that in mixed stands where Douglas fir was only interspersed, mean dbh of the species reached as many as 70 cm. A question of the production of Douglas fir stands is analyzed in detail in the study. The growing stock of Douglas fir stands aged 85–95 years ranged between 460 and 900 m^3/ha.

There is a sufficient number of findings on the production potential of Douglas fir right in the Křtiny TFE. Douglas fir is recorded there in a number of stands generally at mesotrophic sites on an area of more than 130 ha. Some published data on its production are given in the chapter Results and Discussion.

Douglas fir in Křtiny TFE

The Training Forest Enterprise Masaryk Forest at Křtiny serves as a special-purpose institution of Mendel University of Agriculture and Forestry in Brno. The TFE creates the continuous complex of forests north of Brno of the total area of forest land 9,860 ha. This enterprise was established in 1923 and is delimited by the coordinates 49°13' to 49°21'N and 36°16' to 34°28'E.

The TFE is situated in the 1st to the 4th forest vegetation zone (FVZ). Their proportion is as follows:

(1) FVZ – oak	329 ha	3.3%
(2) FVZ – beech-oak	2,787 ha	28.3%
(3) FVZ – oak-beech	5,123 ha	51.9%
(4) FVZ – beech	1,627 ha	16.5%
	9,866 ha	100.0%

As for the proportion of trophic series (Table 1), a mesotrophic series accompanied by an exposed series markedly predominates. The proportion of an acid series is also significant. Difficulties of management are indicated by the considerable proportion of the exposed series. Together with an extreme series they

Table 1. The proportion of trophic series in Křtiny TFE

Trophic series	Forest land	
	(ha)	(%)
Extreme	477	4.8
Exposed	2,092	21.2
Acid	983	10.0
Mesotrophic	6,158	62.4
Gleyed	55	0.6
Waterlogged	2	0.0
Floodplain	99	1.0
TFE total	**9,866**	**100.0**

Table 2. The proportion of tree species in Křtiny TFE (%)

As on	Spruce	Fir	Pine	Larch	Douglas fir	Other conifers	Conifers total	Oak	Beech	Hornbeam	Other broadleaves	Broadleaves total
1. 1. 1993	25.9	1.3	11.3	8.7	***1.1***	0.1	**48.4**	13.9	25.8	7.4	4.5	**51.6**
1. 1. 2003	22.8	1.3	9.6	9.0	***1.3***	0.1	**44.1**	14.5	29.2	7.4	4.8	**55.9**

take up more than a quarter of the TFE area. Gleyed and waterlogged series occur only marginally.

As for the area proportion of tree species a significant decrease in the area of coniferous species occurred at the expense of broadleaved species in the course of the previous working plan (see Table 2). The proportion of spruce (from 25.9 to 22.8%) as well as pine (from 11.3 to 9.6%) markedly decreased. On the contrary, the proportion of beech substantially increased in the course of ten years (from 25.8 to 29.2%); at present broadleaves account for nearly 56% of the area of the TFE forest land. According to the present forest management plan (FMP) (since 1. 1. 2003), in total 660 stand parts with the Douglas fir proportion ≥ 1% are registered. The total area of these stand parts is 2,080.23 ha (21.1% of the TFE stand area), out of this, Douglas fir amounts to 131.24 ha (1.3% of the TFE stand area). In the first FVZ, Douglas fir is registered only in four stand parts (0.5% Douglas fir proportion). Almost $^2/_3$ of all Douglas fir stands (63.3%) are included in the 3rd oak-beech FVZ. The 2nd FVZ takes up 21.5% of stands and the 4th FVZ 14.8% of Douglas fir stands.

Douglas fir occurs in the TFE in all age classes (Table 3). The registration of 115 stand parts of the 1st FVZ with Douglas fir (Douglas fir area 16.86 ha) documents an important position of the species in regeneration targets. This trend has been evident since the mid-80s of the last century when the proportion of Douglas fir in the 1st age class amounted to 31.02 ha (23.6% of the present area of Douglas fir).

Douglas fir in the pole-stage stand (the 3rd to the 6th age class) occurs in the TFE on an area of 22.71 ha (17.3%). The absolutely highest proportion is in the 4th age class. In 1923 to 1942, it was cultivated on 48.68 ha (37.1%). Douglas fir was, however, regularly introduced to forest stands there even before World War I. In the present 10th to 14th age classes, 111 stand parts with the reduced proportion of Douglas fir 17.18 ha are registered in the TFE.

In all age classes, Douglas fir occurs in forest stands mainly in the position of an individual admixture. In 485 stand parts (73.5%), Douglas fir is registered in an interval from 1 to 10% (its reduced area is 51.16 ha). In total in 106 stand parts (area 47.38 ha), the Douglas fir proportion is 11 to 50% and only in 46 stand parts (area 20.76 ha) 51 to 90%. In monocultures (91 to 100%), it occurs in 23 stand parts (area 11.93 ha), out of this number 20 stand parts are, however, registered in the 1st age class.

Table 3. The survey of growing stock and area of Douglas fir according to age classes in forest stands of Křtiny TFE

Age class	Number of groups	Growing stock (m^3)	Species area (ha)	Growing stock in relation to species area (m^3/ha)
0	6	734	1.75	418.45
1	115	0	16.86	0.00
2	42	844	14.16	59.62
3	31	667	3.04	219.21
4	64	2,760	9.01	306.31
5	34	1,654	4.07	406.51
6	53	3,519	6.58	534.41
7	98	15,681	28.31	553.89
8	52	12,033	20.38	590.51
9	50	5,830	9.56	609.76
10	65	6,309	10.39	606.97
11	28	3,272	4.80	681.82
12	11	878	1.44	610.91
13	4	221	0.37	598.75
14	3	151	0.18	835.64
15	1	4	0.01	476.19
16	3	163	0.32	510.33
Total	**660**	**54,720**	**131.24**	**416.95**

Methods and characteristics of research stands

The list and registration of all stands from the forest management plan (as on 1. 1. 2003) for TFE Křtiny with the proportion of Douglas fir ≥ 1% served as a basic database for assessing the production potential of Douglas fir. The list was prepared according to age classes and management groups of stands. As already mentioned, there are 660 parts of stands in the TFE with the Douglas fir reduced area amounting to 131.24 ha.

In the present study, the oldest mature stands in the 9th to the 14th age class are evaluated. In total, 29 stands were assessed, which corresponded to methodical requirements for research investigations. Their list is given in Table 4.

The stands were classified into 6 groups according to age and management sets of stands (MSS). In the 9th age class, three stands were evaluated in MSS 25, five stands in MSS 45. In the 10th age class, again three stands were assessed in MSS 25 and six stands in MSS 45. The oldest group (over 101 years) consists of the set of four stands in MSS 25 and of eight stands in MSS 45. Stand 168B14, Habrůvka Forest District, established in 1871 (age as on 1. 1. 2007 – 136 years) is the oldest evaluated stand with a registered proportion of Douglas fir. Generally, it referred to single-tree mixed or group-mixed stands.

Table 4. Characteristics of experimental stands

Stand	Stand part	Age as on 1. 1. 2007	Management set of stands	Species proportion (%)
27A9		89		Dgl 35, spruce 20, larch 15
50B9	I	89	25	Dgl 40, larch 45
52A9		89		Dgl 8, spruce 20, larch 15
41B9a		91		Dgl 15, larch 25
178A9		86		Dgl 35, spruce 50
312B9	II	86	45	Dgl 20, larch 20
335B9		94		Dgl 10, spruce 76, larch 10
341B9		93		Dgl 10, spruce 10, larch 10
27D10		99		Dgl 6, spruce 14, larch 22
136D10	III	103	25	Dgl 7, spruce 20, larch 30
137E10		102		Dgl 10, spruce 59
108E10a		100		Dgl 10, spruce 12, larch 20
130A10		102		Dgl 65, spruce 30
130B10	IV	96	45	Dgl 25, spruce 10, larch 33
132D10		104		Dgl 15, spruce 25, larch 19
203A10		103		Dgl 5, spruce 6, larch 24
351C10		101		Dgl 10, spruce 43, larch 5
139A12		122		Dgl 3, larch 4
373B12	V	123	25	Dgl 3, spruce 27, larch 41
373C12		124		Dgl 3, spruce 16, larch 29
55B13b		130		Dgl 5, larch 2
142C11		107		Dgl 1, spruce 30
173C11		106		Dgl 4, spruce 91
177B11		106		Dgl 10, spruce 68, larch 20
197A11a	VI	108	45	Dgl 29, spruce 57, larch 6
203B11		114		Dgl 7, spruce 20, larch 40
373A11		109		Dgl 2, spruce 15, larch 15
156D12		118		Dgl 2, spruce 8, larch 28
168B14		136		Dgl 21, spruce 43

In each of the stands, 10 Douglas fir trees with the highest dbh were marked and registered. At the same time, in each of the trees its height was measured. Finally, the volume of trees was calculated according to applicable yield tables. The production potential of other trees of assessed stands, namely spruce or larch, was determined using the same method, i.e. marking the trees in the landscape, registration and measuring of the largest trees. Only trees within the stand parts were included in the evaluation. On the contrary, edge trees, trees along roads, cleared boundary lines, etc. were excluded from the records. In the following text, the results of studies from 6 stands are given in simple tables and, thus, one characteristic stand is presented from each of the groups. The significance of differences in the production potential (volume in m^3) between particular species was evaluated using a one-factor test ANOVA.

Within the study of the production potential of Douglas fir, diameter increment was analyzed retrospectively in three sample trees of an evaluated stand (27A9) using the computer-based image analysis in OSM and PAST programs. The actual increment cores were scanned immediately after sampling (elimination of the effect of shrinkage) and subsequently, they were used in the digital form only.

RESULTS AND DISCUSSION

Basic mensurational data of the largest Douglas fir trees and the largest indigenous conifers, i.e. spruce and larch, in evaluated stands are given in Tables 5 to 10. Remarkable production parameters of Douglas

Table 5. Mensurational parameters of the 10 largest trees in stand 27A9 (age 89 years, MSS 25)

Douglas fir				Spruce				Larch			
Tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)
1	48	79.0	10.00	1	40	57.3	4.14	1	36	63.4	4.20
2	51	75.2	9.78	2	37	58.6	4.06	2	38	59.2	4.16
3	48	75.2	9.21	3	36	54.8	3.53	3	37	58.0	3.88
4	46	75.5	8.82	4	40	50.6	3.46	4	38	53.8	3.64
5	46	71.7	8.16	5	35	52.5	3.23	5	37	55.1	3.60
6	39	75.2	7.48	6	37	51.0	3.20	6	37	55.1	3.60
7	42	72.3	7.48	7	41	48.1	3.20	7	38	48.4	3.07
8	42	70.4	7.08	8	39	48.1	3.05	8	34	52.5	3.02
9	42	68.5	6.79	9	35	51.0	3.03	9	33	53.5	2.96
10	42	67.5	6.79	10	34	50.6	2.94	10	33	50.6	2.72
Mean	44.6	73.0	8.16		37.4	52.00	3.38		36.1	55.0	3.49

Statistical parameters of the largest trees

	Mean	Median	Lower quartile	Upper quartile	Standard deviation
Dgl (volume m^3)	8.16	7.82	7.08	9.21	1.22
Spruce (volume m^3)	3.38	3.21	3.05	3.53	0.42
Larch (volume m^3)	3.49	3.60	3.02	3.88	0.52

fir were noted already in the first evaluated youngest stand 27A9 (Table 5). Top height of the species ranged markedly above 40 m there (the highest Douglas fir 51 m). On average, Douglas fir was 7.2 m higher than spruce and 8.5 m higher than larch. Similarly, the mean volume of 10 Douglas fir trees with the largest diameter (8.16 m^3) was 2.4 times higher than the volume of spruce trees (3.38 m^3) and 2.3 times higher than the volume of larch trees (3.49 m^3).

Table 6. Mensurational parameters of the 10 largest trees in stand 341B9 (age 93 years, MSS 45)

Douglas fir				Spruce				Larch			
Tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)
1	38	82.8	8.58	1	35	61.5	4.05	1	35	53.2	3.14
2	39	70.7	6.82	2	36	52.9	3.32	2	32	54.8	2.90
3	38	71.3	6.64	3	32	55.4	3.13	3	30	58.0	2.85
4	35	66.6	5.52	4	34	49.0	2.75	4	34	49.7	2.76
5	39	63.4	5.50	5	32	49.4	2.59	5	35	46.2	2.54
6	38	63.1	5.37	6	34	46.8	2.57	6	34	44.9	2.36
7	38	62.4	5.21	7	32	48.4	2.50	7	33	44.3	2.18
8	39	58.0	4.74	8	32	46.8	2.42	8	30	47.8	2.15
9	38	57.6	4.62	9	31	47.5	2.34	9	31	45.2	2.06
10	36	58.6	4.52					10	30	45.2	1.96
Mean	37.8	65.4	5.75		33.1	51.0	2.85		32.4	48.9	2.49

Statistical parameters of the largest trees

	Mean	Median	Lower quartile	Upper quartile	Standard deviation
Dgl (volume m^3)	5.75	5.44	4.74	6.64	1.26
Spruce (volume m^3)	2.85	2.59	2.50	3.13	0.55
Larch (volume m^3)	2.49	2.45	2.15	2.85	0.41

Table 7. Mensurational parameters of the 10 largest trees in stand 136D10 (age 103 years, MSS 25)

Douglas fir				Spruce				Larch			
Tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)
1	46	101.0	13.72	1	33	58.3	3.51	1	37	70.7	5.20
2	45	93.3	11.89	2	36	47.8	2.81	2	39	54.8	3.90
3	42	81.5	9.30	3	33	49.4	2.67	3	37	58.0	3.88
4	39	83.4	8.80	4	33	49.0	2.67	4	36	58.3	3.72
5	41	77.7	8.38	5	34	45.9	2.48	5	36	54.5	3.36
6	35	82.5	7.76	6	33	46.2	2.40	6	32	57.3	3.06
7	35	80.3	7.46	7	34	44.9	2.39	7	28	65.3	3.03
8	36	75.8	7.06	8	31	45.9	2.26	8	31	55.1	2.77
9	37	73.2	6.78	9	31	44.6	2.18	9	32	52.5	2.75
10	30	81.5	6.64	10	35	41.4	2.10	10	31	53.8	2.69
Mean	38.6	83.0	8.78		33.3	47.3	2.55		33.9	58.0	3.44

Statistical parameters of the largest trees

	Mean	Median	Lower quartile	Upper quartile	Standard deviation
Dgl (volume m^3)	8.78	8.07	7.06	9.30	2.33
Spruce (volume m^3)	2.55	2.44	2.66	2.67	0.41
Larch (volume m^3)	3.44	3.21	2.77	3.88	0.77

Somewhat lower absolute production parameters were recorded in stand 341B9 (Table 6). Nevertheless, even there the volume of the largest Douglas fir trees is more than the double of the volume of spruce and larch trees.

In the stand part 136D10 (Table 7), evidently a Douglas fir with the largest volume throughout the TFE was recorded (h = 46 m, dbh = 101.0 cm, V = 13.72 m^3).

In the same stand, the largest trees of the same age show the following parameters:

Table 8. Mensurational parameters of the 10 largest trees in stand 203A10 (age 103 years, MSS 45)

Douglas fir				Spruce				Larch			
Tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)
1	43	103.2	13.14	1	37	72.6	5.63	1	42	60.8	5.05
2	45	98.1	12.75	2	40	66.9	5.35	2	40	56.1	4.15
3	39	101.3	11.69	3	39	66.6	5.23	3	32	67.5	3.95
4	42	91.4	10.85	4	40	65.3	5.11	4	40	52.5	3.83
5	37	93.3	9.90	5	40	61.8	4.74	5	34	61.8	3.77
6	41	86.0	9.76	6	39	61.1	4.62	6	37	52.2	3.31
7	38	88.5	9.53	7	36	64.0	4.49	7	37	51.9	3.31
8	39	85.7	9.29	8	33	65.6	4.33	8	34	56.4	3.26
9	41	81.8	9.08	9	37	59.6	4.16	9	35	53.8	3.23
10	45	77.1	9.04	10	36	59.2	3.95	10	34	53.2	3.02
Mean	41.0	90.6	10.50		37.7	64.3	4.76		36.5	56.6	3.69

Statistical parameters of the largest trees

	Mean	Median	Lower quartile	Upper quartile	Standard deviation
Dgl (volume m^3)	10.50	9.83	9.29	11.69	1.53
Spruce (volume m^3)	4.76	4.68	4.33	5.23	0.55
Larch (volume m^3)	3.69	3.54	3.26	3.95	0.60

Table 9. Mensurational parameters of the 10 largest trees in stand 139A12 (age 122 years, MSS 25)

Douglas fir				Spruce				Larch			
Tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)
1	37	98.7	10.83	1	43	59.2	4.71	1	36	62.4	4.10
2	40	90.8	10.33	2	40	61.1	4.62	2	41	47.8	3.43
3	37	88.9	9.28	3	38	57.0	3.94	3	38	50.0	3.25
4	44	76.8	8.84	4	36	51.3	3.11	4	33	55.1	3.04
5	42	78.3	8.58	5	35	50.3	2.93	5	31	57.0	2.92
6	43	75.5	8.24	6	35	48.1	2.74	6	35	49.4	2.79
7	40	76.8	8.01	7	35	46.5	2.55	7	34	50.3	2.76
8	43	73.2	7.85					8	34	50.3	2.76
9	40	75.5	7.67					9	31	54.5	2.69
10	33	81.2	7.18					10	32	50.3	2.52
Mean	39.9	81.6	8.68		37.4	53.4	3.51		34.5	52.7	3.03

Statistical parameters of the largest trees

	Mean	Median	Lower quartile	Upper quartile	Standard deviation
Dgl (volume m^3)	8.68	8.41	7.85	9.28	1.17
Spruce (volume m^3)	3.51	3.11	2.74	4.62	0.90
Larch (volume m^3)	3.03	2.86	2.76	3.25	0.46

Norway spruce $h = 33$ m, dbh = 58.3 cm, $V = 3.51$ m^3
European larch $h = 37$ m, dbh = 70.7 cm, $V = 5.20$ m^3

Stand 203A10 included in MSS 45 (Table 8) also shows comparable data of production capacities of Douglas fir. The volume of the largest Douglas fir trees ranged there from 9.04 to 13.14 m^3 (on average 10.50 m^3) while the volume of the largest spruce trees was 2.2 times smaller and the volume of the largest ash trees was 2.9 times smaller.

Table 10. Mensurational parameters of the 10 largest trees in stand 197A11a (age 108 years, MSS 45)

Douglas fir				Spruce				Larch			
Tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)	tree No.	height (m)	dbh (cm)	volume (m^3)
1	44	92.4	11.51	1	40	69.7	5.70	1	35	70.4	4.68
2	45	88.2	11.06	2	43	65.6	5.57	2	41	59.2	4.66
3	43	89.8	10.93	3	40	68.2	5.46	3	41	55.7	4.30
4	45	86.0	10.69	4	38	65.3	4.86	4	36	62.7	4.20
5	46	84.4	10.57	5	38	64.3	4.74	5	38	59.2	4.16
6	45	85.4	10.52	6	41	60.8	4.73	6	38	57.0	3.95
7	46	82.8	10.37	7	38	62.7	4.63	7	35	49.7	2.87
8	45	84.1	10.34	8	41	58.9	4.49	8	35	47.8	2.70
9	45	81.8	9.96	9	37	62.4	4.39	9	34	47.1	2.51
10	44	82.8	9.93	10	40	58.6	4.38	10	32	49.4	2.45
Mean	44.8	85.8	10.59		39.6	63.7	4.90		36.5	55.8	3.65

Statistical parameters of the largest trees

	Mean	Median	Lower quartile	Upper quartile	Standard deviation
Dgl (volume m^3)	10.59	10.55	10.34	10.93	0.49
Spruce (volume m^3)	4.90	4.74	4.49	5.46	0.50
Larch (volume m^3)	3.65	4.05	2.70	4.30	0.91

Table 11. Mean parameters of the 10 largest conifers in assessed stands of the 9th to the 14th age class in Křtiny TFE

Stand	Douglas fir			Spruce			Larch		
	height (m)	dbh (cm)	volume (m^3)	height (m)	dbh (cm)	volume (m^3)	height (m)	dbh (cm)	volume (m^3)
27A9	44.6	73.0	8.16	37.4	52.3	3.38	36.1	55.0	3.49
50B9	30.8	59.7	4.03						
52A9	40.9	60.0	5.36						
41B9a	35.5	54.7	3.92				32.6	46.5	2.33
178A9	39.0	65.3	5.89	35.9	63.5	4.40			
312B9	39.6	65.6	6.02				32.6	50.4	2.64
335B9	37.5	66.2	5.84	39.0	59.8	4.39			
341B9	37.8	65.4	5.75	33.1	50.8	2.85	32.4	48.9	2.49
27D10	34.8	66.5	5.45	31.2	48.6	2.53	33.2	58.4	3.39
136D10	38.6	83.0	8.78	33.3	47.3	2.55	33.9	58.0	3.44
137E10	45.3	78.3	9.33	42.2	59.7	4.71			
108E10a	37.3	73.5	6.95	35.3	57.0	3.67	34.9	58.8	3.63
130A10	34.2	69.6	5.85				29.7	49.2	2.23
130B10	38.4	76.8	7.61	36.3	63.4	4.48	36.8	57.2	3.79
132D10	40.4	72.5	7.25				35.8	58.7	3.75
203A10	41.0	90.6	10.50	37.7	64.3	4.76	36.5	56.6	3.69
351C10	43.7	86.5	10.48	39.3	61.7	4.64	38.9	65.4	5.03
139A12	39.9	81.6	8.68	37.4	53.4	3.51	34.5	52.7	3.03
373B12	40.4	71.0	7.05				33.9	59.0	3.51
373C12	39.7	73.9	7.42				36.6	58.4	3.89
55B13b	38.6	69.6	6.51						
173C11	40.4	76.0	7.88	35.2	58.0	3.76			
142C11	42.2	77.9	8.58	40.2	59.6	4.49			
177B11	42.2	81.1	9.12	35.4	51.9	3.17	38.5	53.5	3.70
197A11a	44.8	85.8	10.59	39.6	63.7	4.90	36.5	55.8	3.65
203B11	38.8	88.1	9.61				37.1	58.6	4.00
373A11	41.9	71.1	7.30				33.2	57.2	3.23
156D12	30.8	63.4	4.43	33.8	50.9	2.94	34.0	58.2	3.44
168B14	40.9	82.1	9.05	36.9	64.7	4.71			

Data from the oldest part of stands are given in Tables 9 and 10. In all assessed stands all evaluated parameters (height, dbh, volume) are also higher there for Douglas fir, generally markedly higher, than for compared conifers spruce and larch.

This unambiguous finding follows also from Tables 11 and 12, where mean values are given in all 29 assessed stands for the 10 absolutely largest (of the greatest volume) trees in the given age range in the Křtiny TFE.

Differences in mensurational parameters determined for Douglas fir on the one hand and for spruce or larch on the other hand, compared by the one-factor ANOVA test were highly significant. By contrast, the same test did not prove a significant difference between the production potentials of spruce and larch (Figs. 1 and 2). The analysis of the course of diameter increments of three Douglas fir sample trees in stand 27A9 (age 89 years, MSS 25) – see Fig. 3 – was a part of production studies carried out in TFE Křtiny.

In the pole-stage stand (age 15 to 45 years), the diameter increment in sample trees Nos. 1 and 6 ranged from 8 to 13 mm/year, in sample tree No. 4 from 6 to 11 mm/year. In the last 20 years in the stand age of 69 to 89 years, diameter increment decreased below 4 mm/year only exceptionally and in general, it fluctuated from 4 to 8 mm/year (in sample tree No. 4 up to 11 mm/year). Significant variance of the values in the particular years was very probably caused by

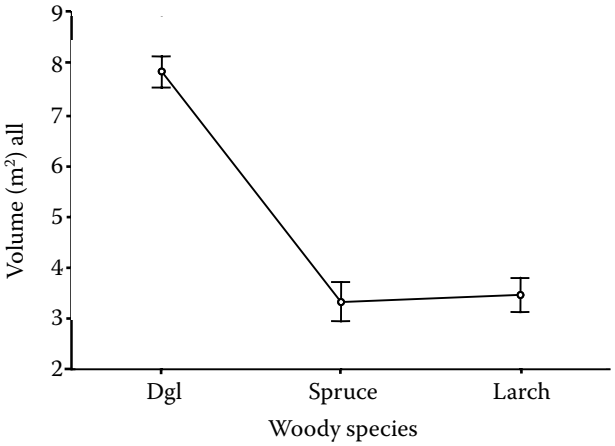

Fig. 1. The significance of differences in the production potential of Douglas fir, spruce and larch (one-factor ANOVA test) in management set of stands (MSS) 25

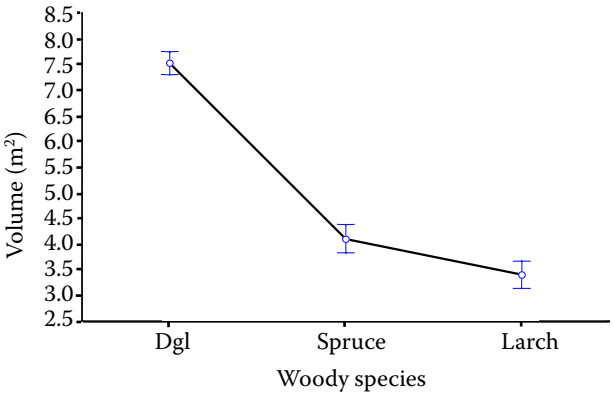

Fig. 2. The significance of differences in the production potential of Douglas fir, spruce and larch (one-factor ANOVA test) in management set of stands (MSS) 45

the fluctuation of climatic parameters or could also be a response to tending measures. Naturally, the permanently high trend of diameter increments manifested itself in volume increment.

Its values in 5-year periods in one sample tree are compiled in Table 13. In the course of the whole period under evaluation of 50 years (age 39 to 89 years), the volume increment ranged between 0.13 and 0.19 m^3 per year. Thus, it is possible to state that at present the largest Douglas fir trees increase their volume by about 1.5 m^3 every 10 years. The high or exceptionally high production potential at mesotrophic sites of TFE Křtiny has been proved also by other authors.

Škoda (1977) compared the production of Douglas fir and spruce in a 70-year stand. The mean height of the stand amounted to 35 m and the mean volume to 2.90 m^3, the mean height of spruce was only 26 m and the volume 0.98 m^3.

In the Křtiny TFE, the production potential of Douglas fir was also assessed by Sedláček (2001) in his MSc thesis. Investigations were carried out in 15 one-hundred-years-old mixed stands. Mean heights of Douglas fir ranged from 29 to 42 m, the volume of the largest trees from 3.27 to 8.61 m^3.

Evaluation of the production of a stand part at a mesotrophic site of Křtiny TFE was finally published by Kantor et al. (2001) and Martiník (2004). In a 68-years-old stand without intentional tending measures, Douglas fir in a mixture with pine, larch, oak, beech, hornbeam and lime showed exception-

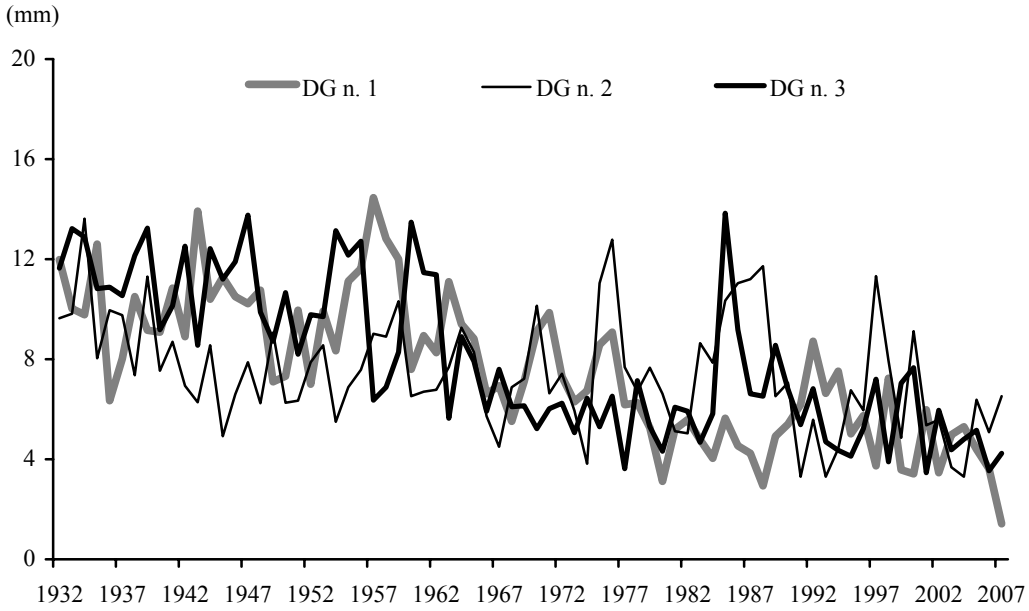

Fig. 3. Annual ring analysis of the development of 3 sample trees of Douglas fir in stand 27A9

Table 12. The largest trees in Křtiny TFE in evaluated stands of the 9th to the 14th age class (MSS 25, 45)

Order	Douglas fir		Spruce		Larch	
	stand	volume (m^3)	stand	volume (m^3)	stand	volume (m^3)
1	136D10	13.72	130B10	6.35	351C10	7.22
2	203A10	13.14	168B14	6.14	351C10	6.58
3	137E10	12.77	168B14	6.12	177B11	5.73
4	203A10	12.75	178A9	5.90	351C10	5.52
5	203B11	12.63	130B10	5.79	373C12	5.31
6	168B14	12.40	197A11a	5.70	136D10	5.20
7	137E10	11.95	203A10	5.63	203B11	5.19
8	136D10	11.89	142C11	5.59	203A10	5.05
9	351C10	11.76	197A11a	5.57	351C10	4.86
10	203A10	11.69	168B14	5.51	351C10	4.77
Mean		12.47		5.83		5.54

ally high parameters. The proportion of Douglas fir increased from 16 to 28% from 1961 to 1999 and the volume from 52 to 232 m^3/ha. Generally, it took a dominant and co-dominant position. Thus, at the mean height of 30.6 m and mean volume 1.66 m^3 the species together with larch and co-dominant beech creates the substance of the production and stability of the stand.

Quite comparable data on the high production parameters of this introduced species were also obtained during studies carried out in Germany (Kenk, Ehring 1995; Burgbacher, Greve 1996). However, the hypothesis of Huss (1996) appears to be improbable. According to the hypothesis, Douglas fir can reach a height of 70 to 80 m at a sufficient rotation even under conditions of Central Europe.

SUMMARY AND CONCLUSION

The present paper evaluates the production potential of Douglas fir growing at mesotrophic sites in mature stands of Křtiny TFE.

In total, 29 mixed stands were assessed with the registered proportion of Douglas fir aged 85 to 136 years. Generally, these were stands at mesotrophic sites in management sets of stands (MSS) 25 to 45.

Comparing 10 Douglas fir trees of the largest volume with the 10 largest spruce or larch trees higher, and generally markedly higher, production potential of the introduced Douglas fir was found in all assessed stands. There were also groups where the volume of Douglas fir was twice to 3 times higher

Table 13. Retrospective analysis of the development of a Douglas fir sample tree in stand 27A9

Year	Age	Height (m)	dbh (cm)	Volume (m^3)	Diameter increment (mm)	Volume increment (m^3)
2007	89	48	79.0	10.01	19.72	0.68
2002	84	46.5	77.0	9.33	23.68	0.72
1997	79	45	74.7	8.61	28.66	0.96
1992	74	43	71.8	7.65	28.16	0.86
1987	69	41	69.0	6.79	23.24	0.65
1982	64	39	66.7	6.14	25.42	0.76
1977	59	37	64.1	5.38	36.88	0.78
1972	54	35.5	60.4	4.60	38.92	0.69
1967	49	33	56.5	3.91	42.88	0.86
1962	44	30.5	52.2	3.05	49.62	0.76
1957	39	28	47.3	2.29		

than the volume of spruce or larch. The largest difference was noted in stands 136D12 (mean volume of Douglas fir 8.78 m^3, spruce 2.55 m^3, larch 3.44 m^3) and 177B11 (mean volume of Douglas fir 9.12 m^3, spruce 3.17 m^3, larch 3.70 m^3).

An objective view on the compared species is evident from Tables 11 and 12, where the mean values are compiled from all 29 assessed stand parts as well as the values of the 10 absolutely largest trees in the given age interval. The variance of assessed mensurational parameters in particular groups is evidently of several courses.

Data on the Douglas fir provenance are missing, nevertheless, it is virtually certain that its origin cannot be uniform at the given range of age (85 to 136 years). Moreover, within a MSS, the production potential of assessed stands can be affected by an actual forest type and, finally, stand tending can also play an important role. Nevertheless, conclusions and findings on the exceptionally high production potential of Douglas fir are quite definite. Generally, it is possible to state that under given site conditions, the production potential of this introduced species is roughly twice higher as compared with domestic conifers – spruce and larch.

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Produkční potenciál douglasky tisolisté na živných stanovištích ŠLP Křtiny

ABSTRAKT: Studie hodnotí produkční parametry (výška, $d_{1,3}$, objem) douglasky tisolisté na živných stanovištích Školního lesního podniku Křtiny v porostech mýtného věku. Celkem bylo posuzováno 29 smíšených porostů s evidovaným zastoupením douglasky ve věku 85 až 136 let. Srovnáním 10 nejobjemnějších douglasek s 10 nejhmotnatějšími smrky, resp. modříny byl bez výjimky ve všech hodnocených porostech zjištěn vyšší, zpravidla výrazně vyšší produkční potenciál introdukované douglasky. Výjimkou nebyly skupiny, kde byl objem douglasek dvakrát až třikrát větší než objem smrků nebo modřínů (tabulky 5 až 10). V porostu 177B11 např. byl zaznamenán střední objem 10 nejobjemnějších douglasek 9,12 m^3, ale objem smrků pouze 3,17 m^3 a objem modřínů 3,70 m^3. Zjištěné rozdíly dendrometrických parametrů douglasky na jedné a smrku, resp. modřínu na druhé straně, srovnávané testem ANOVA, byly statisticky vysoce průkazné. Z letokruhových analýz souběžně vyplynulo, že v současné době se pohybuje v dospělých porostech objemový přírůst jednotlivých douglasek na úrovni 0,12 až 0,16 m^3/rok (tj. asi 1,5 m^3 každých 10 let).

Klíčová slova: douglaska tisolistá; smrk ztepilý; modřín opadavý; produkční potenciál; živná stanoviště

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