Prosperity of Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) plantations in relation to the shelter

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ABSTRACT: The study evaluates the mortality, growth and qualitative characteristics of Douglas fir transplants planted out on clear-cut areas with different shelter. We assessed 11 clearings situated in the Forest Site Complex 4K – acidic beech (*Fagetum acidophilum)*. The young trees were assessed 3 years after planting for the following parameters: total shoot length, increment, root collar diameter, number of multiple stems, stem curvature, crown form, length of needles, colour of needles and frost damage. The lowest mortality and the best growth of Douglas fir plants were recorded in small, sheltered gaps. Large, unsheltered gaps showed low survival, slower growth and poor vitality of plants.

Keywords: forest regeneration; clear-cut area size

Douglas fir is the most important forest tree species introduced into the Czech Republic. The first record of the planting of Douglas fir in the Czech territory dates from 1842, when Douglas fir was planted in the Chudenice arboretum. After the first plantings in arboretums and parks, the species started to be planted also in forest stands in 1876 (Vančura 2010). The share of Douglas fir in the Czech forests is low (ca 0.2%) and concentrated in the first four age classes (Report 2007). Douglas fir is grown rather locally in regions such as southern Bohemia, where it began to be introduced into forest stands.

In the Czech forestry, Douglas fir is an interesting species due to its volume production. On favourable sites, it is the most productive tree species and surpasses all native species (Šika 1977a; Dolejský 2000; Kantor et al. 2010; Tauchman at al. 2010). Douglas fir is potentially a deep-rooting species and on deep, not waterlogged soils, its roots can reach considerable depths, thus contributing to good tree anchorage and storm resistance (Hermann 1977). However, in soils with high groundwater table Douglas fir forms a flat root system which does not provide sufficient stability against wind (Hermann 1977). Compared with spruce. Douglas fir is more drought resistant, produces more favourable humus forms and is more resistant to rots (Jankovský et al. 2006; Podrázský, Remeš 2008; Podrázský at al. 2011). Natural regeneration is easily achievable when appropriate management is applied (Bušina 2006; Kantor et al. 2010). Although not being susceptible to many biotic and abiotic factors in the Czech Republic, young plants may be endangered by physiological drought (Šika 1977a). The affected plants exhibit rusty needles which fall in the spring. Nevertheless, annual shoots would flush as a rule and most trees would recover soon from the damage. The regeneration capacity of Douglas fir seems to be very high because trees had been found completely deprived of needles, which became green again (Hoffman 1964). Furthermore, young Douglas fir plants are endangered by late spring and early autumn frosts. Young Douglas fir is particularly sensitive to the root system drying out. Fungal diseases threatening Douglas fir (interior provenances in particular) are *Rhabdocline*

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pseudotsugae Syd. and *Phaeocryptopus gäumanni* (Rhode) Petr.

Thanks to its positive properties and with respect to possible climatic changes connected with possible decline of autochthonous species or spread of their diseases. Douglas fir should be planted on a much greater scale in Czech forests. Šindelář (2003) recommended a proportion of 2–4% on fertile and acidic sites in Czech forests at altitudes ranging from 350 m to 700 m. Thus, Douglas fir should be planted or naturally regenerated every year on an area of 400–800 ha, for which 1.2–2.4 mil. transplants would be needed.

In connection with the increased interest in Douglas fir and the desired higher proportion in the forests, problems come to the fore with the species artificial regeneration, namely with the high mortality which ranges between 10 and 100% in young plantations. After-planting losses are affected by numerous factors of which the main ones are the planting stock quality, the method and quality of planting, weather at the time of planting and also the clear-cut area size and shelter.

This study aims to assess the influence of clear-cut area size and shelter provided by the adjacent stands on the mortality of young Douglas fir transplants. their subsequent growth and characteristics of stem, crown, needles and frost injury. The main question is whether smaller gaps protected by the stands are more suitable for the planting of Douglas fir or whether the species thrives also on larger open areas.

MATERIAL AND METHODS

Experimental design and data collection

The survey was conducted in the autumn of 2011 on young plantations established by forest practitioners. Bare-rooted transplants were planted in rows on clear-cut areas in the spring of 2009. All eleven surveyed clearings were situated on the forest site complex 4K – acidic beech (*Fagetum acidophilum).* Shelter degree was determined in all clearings. Two clearings had to be divided into parts due to different sheltering of their areas. Thus, there were altogether 14 research plots planted with Douglas fir (Stand A–N). At least 140 plants were measured and assessed on each of the plots. provided that there were so many growing on the plot.

The following parameters were determined in 2011:

– mortality,
– initial shoot length of the plants in 2009 and height increments in 2009, 2010 and 2011,
– root collar diameter in 2011,
– number of forks and triple-stems and their starting height,
– stem curvature – straight, up to three stem diameters and more than three stem diameters,
– crown form – triangular, elliptical, globular, one--sided,
– length of needles in 2011,
– colour of needles – green, yellowish and yellow
– injury by late frost in 2011.

A scale was designed for the classification of the area sheltered by an adjacent stand as follows (1 – the most sheltered plot, 3 – the least sheltered plot):

1 – The width of the clearing is up to 35 m and the clearing is sheltered by an adjacent stand at least on three sides. Its total size does not exceed 0.3 ha. The distance of clearing from the shelter-providing stand does not exceed 1.5-fold of its height.

2 – The clearing or its surveyed part is sheltered by an adjacent stand on two sides, and the distance of the clearing or its surveyed part from the shelter-providing stand does not exceed 1.5-fold of its height. Its total size does not exceed 0.3 ha.

3 – The clearing or its surveyed part is sheltered by an adjacent stand on one side or is not sheltered at all.

Applied statistical methods

Differences in mortality. height increments. diameter increment and length of needles detected on the plots with different shelter were analysed using the Kruskal-Wallis test, $\alpha = 0.1$; in the tables statistically significant differences are marked by letters a or b.

Planting stock

The planting stock used was bare-rooted in all cases. Provenances used in individual stands are listed in Table 1. Average shoot lengths of transplants before planting in the stands differed (Table 3). The smallest planting stock of Douglas fir was used in stand M (average shoot length 17.1 cm). The largest planting stock of Douglas fir was used in stand H (average shoot length 58.8 cm). The density of plantations established by hole planting was 3,000 indd·ha^{-1}. During the time of observation. the plants were given a standard care without fertilization.

Table 1. Provenances used in the stands

Stand	Provenances
A, F, G, H, J, K, L	46035 Lake city Coastal provenance
D, M	45165 Knouff lake Interior provenance
B, I	B/Dg/011-/15-5/PE Czech provenance
C, N	CZ-2-2A-DG-3276-10-3-C Czech provenance
F	CZ-1-2C-DG-412-46-4-H Czech provenance

RESULTS AND DISCUSSION

Mortality

Summarized data arranged according to the degree of shelter are presented in Table 3. where mortality on the plots ranged from 17.4% (plots A) to 82.0% (plots N). Cole and Newton (2009) found large differences in Douglas fir mortality (ranging from 8% to 73%) after transplanting. The high mortality risk of planted Douglas fir was corroborated by Šika (1977a). Mauer (2011) reported that losses after the spring planting of Douglas fir transplants into moist soil ranged between 9% and 25% according to the date of planting while losses after the planting into dry soil were from 40% to 62% according to the date of planting. In both cases, the lowest mortality was observed after planting at the phase of bud burst. Mortality values detected on the plots according to the degree of shelter are shown in Table 2. Average mortality values in the clearings with shelter degree 1 and 2 are similar (22.7% and 25.9%); however. on the plots without shelter (shelter degree 3), the mortality is much higher (67.5%). The shelter seems to have a positive influence on the after-planting survival of plants. Insufficiently sheltered gaps (shelter degree 3) seem to be unsuitable for planting Douglas fir. These findings are in a good agreement with the statements of Jirkovský (1962), Hoffman (1964) and Cafourek (2001) did not recommend the planting of Douglas fir in the large clearings and plots fully exposed to sun and wind. Petersen (1982) corroborated the beneficial influence of shelter on the survival of transplants and claimed that the shelter minimizes the occurrence of environmental stresses. Helgerson and Bunker (1985) informed that the shelter has a highly positive influence on the low-vitality planting stock or on transplants outplanted under unfavourable conditions. Klinka et al. (2000) stated that in dry climate Douglas fir requires the protection against intensive solar radiation while in wet climate the species requires the ample light. In areas with higher precipitation amounts, the mortality in clearings not sheltered by the surrounding stand may be lower than that detected by us.

Height increment

The height increment of surveyed plants was small in the first year after planting due to transplant shock. The average height increment in the clearings with shelter deg. 1 was 10.1 cm (Table 4). The average height increment in the clearings with shelter deg. 2 and 3 was lower in the first year after planting than in the clearings with shelter deg. 1 (8.9 cm and 8.1 cm); the differences were however statistically non-significant.

Khan et al. (2000) came to a similar conclusion. In their study the largest height increment in the first year was shown in 75% sheltered Douglas firs while less sheltered plants and plants without shelter showed signs of stress in the first year (light colour of needles). Plants growing on the plots with shelter deg. 1 are apparently less stressed by moisture stress, solar radiation, excessive wind, and do not suffer such a great shock from transplanting as the plants on the other clearings. Haase and Rose (1993) claimed that the small height increment of Douglas fir in the first year after planting is caused by moisture stress and by root system re-establishment with the transplants featuring larger root systems. which exhibit lower symptoms of the shock.

As for the mean height increment of the plants in the three-year period. the maximum value was found on the plots with shelter deg. 1–90.9 cm (Table 4). Lower increments were recorded on the plots with shelter deg. 2 (85.6 cm). The lowest increments (64.4 cm) were detected on the plots with shelter deg. 3. Summarizing the results, we can agree with Šika (1977b) that the species is not appropriate for large clearings. However, we

Table 2. Mortality according to the degree of shelter

Shelter degree	1	2	3
Mean mortality (%)	22.7[a]	25.8[a]	67.5[b]

[a,b]indicates statistically significant differences at $\alpha = 0.1$ as detected by the Kruskal-Wallis test

Table 3. Douglas fir – growth characteristics according to the degree of shelter

Stand			A	B	C	D	E	F	G	H	I	J	K	L	M	N
Shelter degree			1	1	1	1	2	2	2	2	3	3	3	3	3	3
Losses	(%)		17.4	22.2	22.2	29.1	20.0	26.4	27.9	29.2	46.2	60.6	69.8	70.5	76.0	82.0
Shoot length		2011	164.4	106.1	100.7	156.0	104.0	148.3	148.3	141.3	110.5	135.3	132.0	81.7	66.6	97.7
		2009	55.4	44.2	21.5	42.6	31.0	52.0	52.0	58.8	49.9	52.0	55.0	32.1	17.1	24.7
Increment	(cm)	2009	11.1	7.6	9.7	11.9	6.9	9.6	9.4	9.8	9.3	9.4	9.2	6.5	5.3	9.2
		2010	39.8	19.8	26.7	38.2	25.4	29.7	32.6	27.8	21.2	29.3	21.5	13.5	13.9	32.4
		2011	58.2	34.4	42.8	63.3	40.7	51.2	54.3	44.9	30.1	44.6	39.8	29.7	30.4	31.4
Total height increment (cm)			109.0	61.9	79.2	113.4	73.0	90.4	96.3	82.5	60.6	83.2	70.5	49.7	49.6	73.0
Root collar diameter (mm)			24.5	18.5	11.7	23.3	19.6	27.1	23.1	24.1	18.9	24.0	24.2	16.9	15.2	16.0
Plants with multiple stem (%)			20.1	65.1	31.0	15.7	35.5	17.3	24.7	14.7	60.9	32.5	16.9	29.4	43.8	38.1
Stem curvature		straight	58.3	22.8	29.4	68.7	41.5	42.0	78.5	61.3	17.7	52.2	55.1	32.5	36.0	38.1
		≤ 3 stem diameters	30.5	44.9	42.9	23.9	48.0	28.4	9.7	26.7	52.1	24.6	32.9	47.3	38.4	36.5
		≥ 3 stem diameters	11.2	32.3	27.8	7.5	10.5	28.4	11.8	12.0	30.2	23.2	12.0	20.2	26.4	25.4
Crown form	(% of plants)	triangular	53.3	26.2	5.6	50.7	38.0	46.9	45.2	48.0	18.3	41.4	22.3	6.7	11.6	34.9
		elliptical	28.4	38.8	76.2	28.4	35.5	29.6	14.0	26.7	40.2	20.7	48.5	38.8	26.9	52.4
		globular	9.7	6.8	4.0	3.0	7.0	18.5	16.1	12.0	10.2	18.7	16.6	23.4	28.9	7.9
		one-sided	8.7	28.6	14.3	17.9	19.5	4.9	24.7	13.3	31.3	19.2	12.6	31.2	33.5	4.8
Colour of needles		yellow	0.7	3.9	0.0	0.0	0.0	0.0	1.1	0.0	0.3	0.0	5.3	10.0	2.1	0.0
		yellowish	8.7	5.2	3.2	1.5	6.0	8.6	15.1	17.3	4.2	14.8	26.6	38.0	24.4	7.9
		green	90.7	91.3	96.0	98.5	94.0	91.4	83.9	82.7	95.6	85.2	68.1	52.0	74.4	92.1
Length of needles (mm)			27.1	29.1	24.2	29.2	26.1	29.3	26.2	25.9	26.7	27.1	25.0	23.1	21.3	23.1
Frost injury (in % of plants)			10.9	94.2	42.9	0.0	53.5	22.2	31.2	6.7	62.0	21.2	11.3	47.9	64.0	41.3

Table 4. Height increment in the first year, total height, diameter increment and length of needles according to shelter degree

Shelter degree		1	2	3
Mean height increment in 2009	(cm)	10.1	8.9	8.1
Mean total height increment	(cm)	90.9	85.6	64.4
Mean diameter increment	(mm)	19.5	23.5	19.2
Mean length of needles	(mm)	27.4	26.9	24.4

cannot agree with his statement that Douglas fir is generally unsuitable for repair planting due to its slow height growth during the first five years because we found out that the height increment of this species three years after planting can reach 40–60 cm. An exception was stand B where the reason for the low height increment was frost injury and a high number of plants with multiple stems.

Rose et al. (1999) studied Douglas fir plantations in their home country on unsheltered plots and informed that the shoot length of plants three years after planting reached 112–203 cm. This is more than on our unsheltered plots (shelter deg. 3) where the shoot length ranged from 66.6 cm to 135.3 cm. Cole and Newton (2009) claimed that the height of 10-year-old Douglas firs should be 6–10 m (average height increment 60–100 cm).

Diameter increment

Diameter increment in the first post-planting years is not as important as height increment since the young plants need to cope with the impact of weeds and wildlife as fast as possible. The root collar diameter is not affected by the stand shelter. The largest-diameter root collars (23.5 mm) were found with shelter degree 2 (Table 4). Root collars of lower-diameters were recorded with shelter degrees 1 and 3 (19.5 resp. 19.2 mm). Larger root collar diameters were recorded in more advanced transplants.

Multiple stems and damage

Great variability was found in the number of plants with multiple stems. Multiple stems were developing throughout the years 2009–2011. The percentage of plants with multiple stems ranged from 14.7% to 65.1% (Table 3). The highest percentages of plants with multiple stems were recorded in the stands (B and I) which had suffered the most from severe late frost in 2011. Interestingly, the planting stock in these two stands was of the same provenance. Stand B was severely injured by frost in spite of the sufficient shelter. The reason might have been insufficient frost hardiness of the used provenance or more severe frost in these stands. It appears that frost damage to plants greatly affects the development of multiple stems. Fig. 1 shows a strong correlation of spring frost damage in 2011 with the number of multiple stems. Plots that suffered more severe frost damage in 2011 had been more affected by frost in 2009 and 2010, which had resulted in the development of multiple stems. Similarly. Jirkovský (1962) claimed that the injury to the terminal bud, caused by frost or by careless handling at planting, often leads to the formation of multiple stems. Our Douglas firs had most frequently straight stems or crooked up to three stem diameters (Table 3). Stands with a higher number of multiple stems exhibited more plants with crooked stems.

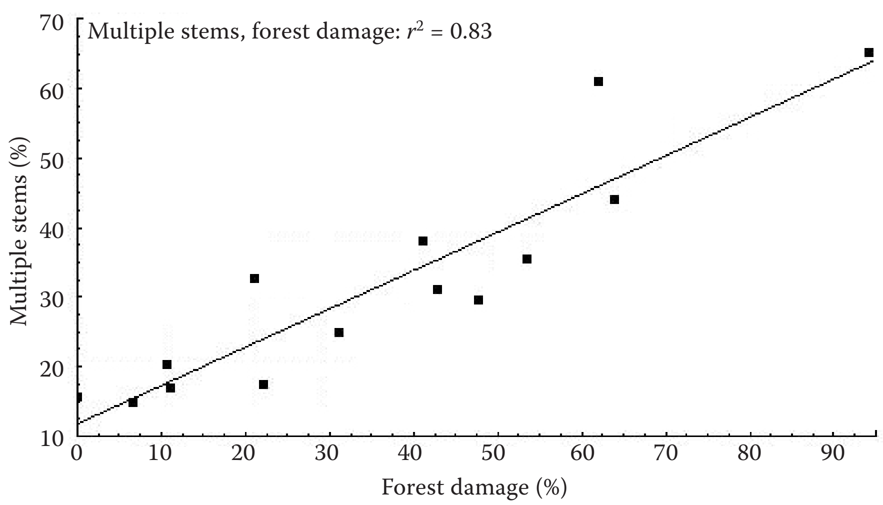

Fig. 1. Dependence of frost injury on the number of multiple stems

Crown form and needles characteristics

The most frequent crown forms were triangular and elliptical (Table 3). Clearings with higher frost damage exhibited increased numbers of plants with one-sided or globular crowns.

The colour of needles hints on the vitality of young trees. Plants that are not perfectly vital have yellowish or yellow needles. The proportion of green needles was lower in unsheltered plants (Table 3). The variability of colours on the plots with shelter deg. 3 might have been due to different provenances, maybe some provenances could adapt themselves to the open-field conditions within the three years. A similar hypothesis may hold also to the length of needles. Young trees on plots with different shelter had a different length of needles (Table 4). The longest needles were found on the plots with shelter deg. 1. shorter and shortest needles were observed on the plots with shelter deg. 2 and 3, respectively.

CONCLUSION

The subject of the study was the development of young Douglas fir three years after planting with regard to different shelter regimes. Conclusions from our survey are as follows:

– For the growing conditions on the experimental sites the most suitable for artificial regeneration of Douglas fir appear to be smaller clearings (gaps), the width of which is below or equal to 35 m and which are sheltered by adjacent stands. Such gaps provide good protection of trees against intensive solar radiation and wind.

– Favourable growth and low mortality were recorded in gaps or their parts, in which the young plants were protected from intensive solar radiation and wind on two sides.

– Large clear-cuts, in which the adjacent stands do not protect the young plants, are inappropriate for the planting of Douglas fir, since a mortality rate up to 80% has to be expected. As for the few surviving plants, their development is slower than under better sheltered conditions. A part of the plants may exhibit low vitality even after three years as well as yellowish or yellow colour of needles.

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